This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

3433 06641461 0

PGW
Rogers

[illegible]

[illegible]

VAN NOSTRAND'S SCIENCE SERIES.

16.

A GRAPHIC METHOD FOR SOLVING CERTAIN ALGEBRAIC EQUATIONS. By Prof. GEORGE L. VOSE. With Illustrations.

17.

WATER AND WATER SUPPLY. By Prof. W. H. CORFIELD, M.A., of the University College, London.

18.

SEWERAGE AND SEWAGE UTILIZATION. By Prof. W. H. CORFIELD, M.A., of the University College, London.

19.

STRENGTH OF BEAMS UNDER TRANSVERSE LOADS. By Prof. W. ALLAN, author of "Theory of Arches." With Illustrations.

20.

BRIDGE AND TUNNEL CENTRES. By JOHN B. McMASTER, C. E. With Illustrations.

21.

SAFETY VALVES. By RICHARD H. BUEL, C. E. With Illustrations.

22.

HIGH MASONRY DAMS. By JOHN B. McMASTER, C. E. With Illustrations.

23.

EXPERIMENTS UPON THE STRENGTH OF VARIOUS METALS. From the German of Prof. LUDWIG SPANGENBERG. With Illustrations.

SCIENCE DEPT.

Rogers

18mo, boards 50 cents.

PGW

THE
MAGNETISM
OF
IRON VESSELS
WITH A
SHORT TREATISE
ON
TERRESTRIAL MAGNETISM.

By FAIRMAN ROGERS,
Member of the Compass Commission of the National
Academy of Sciences.

NEW YORK:
D. VAN NOSTRAND, PUBLISHER,
23 MURRAY AND 27 WARREN STREET.
1877.

Kvs SCIENCE DEPT.

ASTOR LIBRARY
OCT
9
1878
NEW-YORK.

1030

PREFACE.

THIS short treatise on the Magnetism of Iron Vessels was originally prepared for a Manual, similar to the English Admiralty Manual of Scientific Enquiry, which the Bureau of Navigation of the Navy Department purposed publishing.

The publication of the Manual having been abandoned, the article was contributed, by permission of the Bureau of Navigation, to *Van Nostrand's Engineering Magazine*, and is now published in the Science Series.

The original object of the article will explain its form and characteristics. It does not contain any material hitherto unpublished, but it was intended to give to an officer, previously unacquainted with the subject, sufficient information to enable him to undertake a series of observations which would be of value in adding to the general knowledge of the subject, or in studying his own ship so as to avoid mishaps from a too firm reliance upon uncorrected compasses, or from unexpected changes in new magnetic latitudes.

The large table, giving an analysis of the parts of the deviation, is entirely new, and, it is believed, makes that portion of the subject quite clear.

The treatise is offered to those engaged in navigation, especially to yachtsmen and scientific travelers, as a simple introduction to the subject and a guide in such observations as they may feel disposed to undertake.

F. R.

June, 1877.

TERRESTRIAL MAGNETISM

AND

THE MAGNETISM OF IRON VESSELS.

1. THERE are two general matters in connection with magnetism to which the attention of those interested in navigation may be directed.

First—Terrestial Magnetism; in which the seamen is interested on account of the action of the magnetic needle and its variations.

Second—the Magnetic Action of the Iron composing a portion, or the whole, of a ship and its machinery.

2. The fact that a steel needle magnetized by rubbing with natural magnetic iron or loadstone will point towards the

north pole of the earth was at first attributed to some attractive power in that direction drawing the needle towards it.

The simple experiment however of floating such a needle upon water will show by the fact of the needle merely assuming the usual direction without moving towards the northern boundary of the vessel containing it, that the force acting upon the needle, is a directive force, not one of attraction for the needle as a whole.

Experiment further shows that if we pass a galvanic current, generated by any of the ordinary batteries, through a coil of wire, a magnetic needle suspended within this coil will place itself at *right angles* to the direction of the current.

It is therefore inferred from this and more elaborate experiments, that the compass needle points to the north in obedience to the law which causes it to take a position at right angles to currents which are passing around the earth in a direction nearly parallel to the equator, and from West to East. Whether these currents are wholly on the surface of the earth, or partly in the atmosphere, is a question not yet determined, but Faraday considered that currents in the atmosphere produced by the action of heat upon the component gases which are magnetic bodies will account for the diurnal variations which are observed.

Barlow wound wire round a globe in a direction as nearly as possible that of the supposed currents as indicated by observation, and then covering the surface with the engraved paper of the globe found that a magnetic needle suspended over different points of its surface acted, while the currents were passing, exactly as the needle does at the same points upon the surface of the earth.

3. The hypothesis that the earth is a magnet just as a sphere of steel might be, having two poles, North and South, also accounts for most of the phenomena observed as will be shown when treating of the dip, and the two hypotheses have

been connected by supposing, as was suggested by Ampere, that a magnet owes its power to currents which are circulating around it in planes perpendicular to its axis as we have supposed in the case of the earth.

4. For the means of producing electric and galvanic currents, the reader is referred to any elementary books in which the different forms of battery are described; but it is necessary to notice that currents are readily formed by changes of temperature, or by the contact of bodies of different temperatures. Thus the most delicate instrument for comparing temperatures known to the physical investigator is Melloni's thermo-multiplier, which consists of a number of bars of zinc and antimony so arranged that their ends are alternately soldered together and placed in a pile, the two ends of which may be subjected to different degrees of heat. Upon bringing any source or reflector of heat near one end of the pile, the other retaining its former temperature, a galvanic

current is instantly set up, which being properly conducted away by wires, will indicate by its action in deflecting a magnetic needle the most minute changes of temperature.

Such action by the sun upon the earth and upon the atmosphere must give rise to currents which possibly supply the whole magnetic force of the earth, and which, at least, manifest themselves in those diurnal and periodic variations, the determination of which is a part of the object of our observations in terrestrial magnetism.

While the larger portion of the variation is constant for any one place at a given time, there are small parts of it which vary continually, and there are magnetic storms which, sweeping in a regular track, show themselves upon all the instruments which are placed upon their path. We do not refer to thunder storms, but to violent changes of magnetic condition which are only visible through their action on the needle.

Such magnetic disturbances generally

accompany displays of the Auror
alis, and observations made duri
continuance of remarkable Auror
pecially in high latitudes, are inte
and important.

We may compare the constant
the variation to the average he
the sea water along a shore—the
and periodic part, to the tides re
each day and varying with the s
and the irregular variations to th
regular changes in the tides
change of wind and the effects
tant storms.

5. To whatever causes we ma
ute the action of the magnetic
a large number of observations
quired to furnish the data upo
the true theory is finally to be f
and the numerical value which wi
as a basis for calculation.

These observations are at pre
rected to the *direction* of the n
different parts of the earth's
with reference to the true merid
the geodetic north pole, and to

of the needle or the direction with reference to a horizontal plane, which a needle accurately balanced before being magnetized assumes after being magnetized.

In both these cases the *amount* of the directive force as well as the position assumed is to be measured.

The force acting upon the needle in the direction of the dip at any given place, is called the *total force* of the earth at that place.

In other words, the force acting upon the compass needle is not simply one in a horizontal plane directing the needle towards a magnetic pole, but it is a force acting in an inclined direction, which we divide for practical purposes and for convenience of observation and consideration, by a well-known device in Mechanics, into a horizontal component and a vertical component.

The compass needle being acted upon by this inclined force, the vertical component is neutralized by weighting the compass card near the south end of the needle, so as to keep it hanging in a horizontal position, while the horizontal component directs it into a north and south position. As is well known, the vertical component force changes in value with changes of latitude, and the compass card requires readjustment by the addition or subtraction of weight at the south end to enable it to preserve its horizontal position.

6. We frequently speak in a rough way as if the needle pointed to a distinct magnetic pole different from the geodetic pole. This is not strictly true, for there appear to be two north magnetic poles and two south magnetic poles, and the poles of dip or those places at which the needle stands in a vertical position, that is with a dip of 90°, do not coincide with the places of maximum intensity of the total force.

In practice, in latitudes ordinarily visited by the navigator, this complication of the simple law is not important, since the variation at any given place will have a sufficiently slow and regular rate of change to be determined and predicted within practical limits.

This change of variation is caused by the change of position of these magnetic poles, or, at any rate, by some change of condition of the magnetic elements of the earth, which alters the position of these poles as it does the declination, dip and total force at all other places.

For a more complete consideration of this part of the subject, the reader is referred to more elaborate treatises on terrestrial magnetism.

7. The direction of the horizontal component can be readily observed, by comparing the direction of the needle with that of the true meridian, obtained by observations upon the north star, or the sun, or by any of the means well known to seamen.

The deviation from the true north line is called the *variation of the compass*, and differs in different localities and at different periods. It also changes slightly at the same place during each day, giving us the diurnal variation.

This is, however, too small to be of practical importance to the navigator.

The variation is of the utmost importance, as in some localities ordinarily visited by the navigator, it is as great as 50° to 60°, or four to five points to the West, so that when heading due North, magnetic, the ship will be sailing N.E. or N.E. by E.

The accuracy of the determination of this variation, will depend upon the method used to determine the direction of the true meridian, and the means used to measure the angle between it and the direction of the needle.

On board ship the variation is usually determined by observing the magnetic bearing of the sun at noon, with an azimuth compass, or if in a harbor, the magnetic bearing of some distant object such as a building or lighthouse, the correct bearing of which from the ship is known from a chart.

Such determination is sufficiently accurate for ordinary purposes.

The more careful one with the portable declinometer, is described further on (11).

8. The measure of the intensity of the horizontal component is a matter of much greater difficulty and requires nice apparatus and indirect means of obtaining the result.

If a needle which has always the same amount of magnetism, is delicately suspended and deflected a certain number of degrees from the magnetic meridian, it will oscillate about that meridian, coming to rest more or less quickly as the directive force at the place is greater or less; and by using this magnet in different localities the *relative* force at those places can be measured.

There are however two conditions affecting the time of vibration besides the force itself, the amount of magnetism of the needle and its form and weight as affecting its oscillations.

As we cannot insure the first being constant in any needle, and as more than one needle must be used, if we wish simultaneous observations by different observers, some method of eliminating these conditions must be employed.

The amount of magnetic force of the needle itself, is determined by measuring its action upon another needle which is first vibrated under the action of the earth alone, and then under the combined action of the earth and the needle whose power we wish to determine.

The effect of its own mass upon the vibrations is determined by vibrating it first alone, and then with a known weight called the inertia ring, and comparing the result.

The instrument used for these observations in the Navy, and in the Survey of the Coast of the United States is in effect that designed by Gauss & Weber, and made by Jones of London, with such modifications as have been suggested by its use. Mr. Hilgard, of the Coast Survey, has lately devised an improved form which is much more convenient in practice.

DIRECTION OF NEEDLE.

The portable declinometer, which is used to determine the direction of the needle and the horizontal force, consists essentially of a hollow cylindrical magnet suspended by a single thread, so that it may turn with great freedom.

This magnet is closed at one end by a plane glass plate, on which an arbitrary scale is engraved, and at the other by a lens.

At a distance of eight or ten inches from the center of the magnet, and at the same height, is a telescope mounted so that it can be moved in altitude and in azimuth.

When the telescope is so directed that a certain central division of the magnet scale determined by experiment, is cut by the vertical hair of the telescope, the telescope then points in the magnetic meridian, and by comparing this direction with the direction of true north, determined by astronomical observation, the declination or variation is determined with more accuracy than is obtainable with an azimuth compass or an ordinary surveyor's transit.

This same instrument is adapted to the determination of the horizontal force, or the force which, when the magnet is deflected from its position in the magnetic meridian, acts to bring it back to that position.

If the needle is thus deflected and then permitted to swing, it will vibrate until it comes to rest in the magnetic meridian, and it will vibrate with greater or less rapidity as the force drawing it into position is more or less strong.

But the rapidity of vibration will depend, with the *same* horizontal force, upon the magnetism of the magnet itself and this must be determined in order that we may compare experiments made with different magnets.

To do this the magnet observed upon, is dismounted and another substituted in the suspension, and the original one is placed at a measured distance usually from one and a-half to two feet from the suspended magnet in a line at right angles to the meridian. This magnet produces a deflection in the suspended magnet proportional to its own magnetic force and thus this force can be measured. This experiment is repeated with the magnet at different distances.

By making observations then with the original magnet suspended, the horizontal force at the station is determined without reference to the charge of the magnet itself.

There is still the inertia of the vibrating magnet to be eliminated, and this is determined by comparing its vibrations, when loaded with a brass ring of known weight, with its vibrations when unloaded.

10. The details of arrangement of the declinometer are as follows. As the magnet must be shielded from the action of the wind it swings in a wooden box $4\frac{1}{2}$ inches long, 2 inches broad and 2 inches deep, from the top of which a glass tube 8 inches high and $\frac{8}{10}$ inch diameter rises, opening into the box at its lower end. On the top of this tube is a

brass cap capable of being turned around upon its mounting and so graduated on its edge that the amount by which it is turned may be measured. Through the center of this cap passes the pin to the lower end of which the suspension thread is fastened and this pin can be moved vertically by means of a rack and pinion so as to raise or lower the magnet. Suspended from this pin by an untwisted thread of silk fibre, made of as few filaments as possible, is an open brass stirrup or cage which receives the magnet.

The magnets, of which there are two, are hollow steel cylinders of $\frac{7}{10}$ outside and $\frac{11}{20}$ inside diameters and 3.15 and 3.85 inches in length with a lens at one end and a plane glass at the other on which a fine scale is engraved.

The lens is usually in the north end of the magnet and the scale in the south end. These magnets are called collimator magnets; some of the other forms of instruments have solid magnets, which carry a small mirror to reflect a scale placed on the telescope. In this case the telescope must be one of short focus, while with collimator magnets the ordinary theodolite telescope can be used; the lens in the magnet being arranged to give distinct definition of the scale with such a telescope.

A solid brass weight of the same form and diameter as the magnets is also provided.

The box in which the magnet swings is provided with three levelling foot screws and with a screw by which it is made fast to the top of the wooden table on which it rests, which table is in turn supported by a tripod from the ground.

The table is sufficiently wide to hold the magnet box, and sufficiently long to take upon it the telescope at a distance of eight or ten inches from the center of suspension of the magnet.

The telescope used is in fact an ordinary small theodolite (about a five inch circle), which permits the telescope to have a motion in azimuth and altitude.

It should be finely divided and have

two verniers to the horizontal limb. It is screwed on to the table in the proper position.

The magnet box has small windows in the ends of plate glass with parallel faces through which the magnet is observed.

A wooden rod about four feet long is so arranged as to be screwed to the bottom of the magnet box and carries, sliding upon it, carriages to receive the deflecting magnet and to hold it at a given distance from the suspended magnet and at the same height. Wooden blocks to fit into the magnet box on the sides of the magnet to hold it firm, a brass inertia ring, plummet, copper damper for calming the vibrations of the magnet, screw driver, thermometer, pocket compass, spare screws, spool of silk fiber, cement, a small circular mirror which fits into the end of the magnet box and sometimes a small lamp, complete the apparatus.

11. Observations with portable declinometer for declination (variation) and horizontal intensity.

The object is first to determine the direction of the magnetic meridian with reference to the true meridian. This is a matter of observation and not of calculation.

Secondly—To determine the relative proportions of the force of the earth and of the magnet employed, or $\frac{m}{x}$, and the product of m and x or mx, m representing the magnetic moment of the magnet, x the horizontal component of the earth's force.

From $mx=a$ and $\frac{m}{x}=b$, we will have $m=\frac{a}{x}$ and $m=bx$, $\frac{a}{x}=bx$ or $x^2=\frac{b}{a}$.

And the value of m can be obtained in a similar way.

Set up the tripod with the plummet over the marked point of the station, fasten the wooden table upon it with its larger dimension north and south, the magnet box end towards the south, for magnets which have the scale in the south end, level it as nearly as possible, then fix the magnet box upon the table, screwing it up until the long brass spring comes into action.

By means of the three foot screws of the magnet box level it; observe whether the glass suspension tube is tight and vertical.

Screw the theodolite into its place and level it carefully.

Take off the sides of the magnet box, remove the wooden stick from the stirrup, put the brass bar in the stirrup, and allow it to hang until the twist is taken out of the suspension fibers.

If it is necessary to put in new fibers, be sure that they are all equally stretched, so as to bear the weight and use no more than are necessary to sustain the magnet.

When the bar hangs quietly, turn the upper cap of the glass tube gently until the bar hangs in the magnetic meridian as nearly as can be judged. Replace the bar by the magnet, taking care that no turn is introduced into the suspension thread.

Direct the light into the south end of the magnet by adjusting the circular mirror. The magnet will hang in the magnetic meridian, and if the sides of the magnet box are not parallel with it, the table must be turned upon the tripod until they are so, after which the levels must be examined and the box and theodolite re-levelled if they are out. The magnet must be raised or lowered by the rack at the top of the tube and the theodolite adjusted until the scale of the magnet is distinctly seen through the telescope. The axis of the magnet must be now determined.

Direct the telescope to a division near the middle of the scale, clamp it and record the reading. Open one side of the magnet box, rotate the magnet in its stirrup, so that the scale will be inverted, read and record.

Repeat this several times, and the mean of the means of the readings will be the axial division of the scale. Example:

$$\begin{array}{rccl}\text{Scale erect}\left\{\begin{array}{c}71.0\\71.3\\72.0\end{array}\right. & & \left.\begin{array}{c}84.2\\84.8\\83.6\end{array}\right\}\text{Scale inverted}\\ \hline & \underbrace{71.43 \qquad 84.2}_{77.81\text{ is axial div. of scale.}} & \end{array}$$

Now direct the telescope to this division, and it will point in the magnetic meridian.

The direction of the astronomical meridian passing through the same point having been previously determined by any of the observations on the sun or the north star familiar to navigators, and marked, the angular difference between those two directions will be the declination or variation.

Note—After putting the magnet into the stirrup, it may be steadied and brought to rest by the wooden block which is made to fit into the magnet box. After the box is closed, the vibrations may be calmed, and the magnet brought to rest by the use of the screw driver which accompanies the apparatus, and which is generally magnetized so as to have its point a north pole.

Holding this in the hand on either side of the magnet box, while looking through the telescope, a very little practice will enable the observer to regulate the vibrations of the needle with great facility.

12. OBSERVATION FOR HORIZONTAL INTENSITY.

Put in the block to keep the magnet steady and to prevent a twist being introduced into the thread. Take off the magnet box, and screw the long deflection rod to its place under the box, replace the box, and the rod will extend to the E. & W. on both sides. Place the magnet carriages upon the rod. Place the magnet *with which* the vibration experiments are to be made, the longer one upon the West carriage with its North end to the West, and at a given distance from the center of suspension of the magnet.

Suspend the other magnet in the stirrup, taking care that it is at the same height as the deflecting magnet. If the suspended magnet is not horizontal, slide the brass ring upon it to adjust it.

Note the time and the temperature, (see form of record, Form I), then note the scale reading. As the magnet will not come absolutely to rest in a reasonable time, you must read the divisions to which it swings to the right and left, and their mean will be the true reading as in

Form I, line 7 152.5 157.5 Mean=155.0
and line 8 32.0 33.5 “ =32.75
&c.

Reverse the deflecting magnet in its carriage, so that its north end will be east. The suspended magnet will move towards the other end of its scale.

Read and record as before, 32.0 33.5, &c.

Reverse again, record and reverse, and there will thus be two readings for each position of the magnet. The difference between the means of these observations will be the angular distance through which the magnet is deflected. Form I, line 11.

Now place the deflecting magnet in the carriage, which is to the east of the suspended magnet, and observe and record as before, recording the temperature at the end of the observations.

The mean of the two differences thus obtained:

Ex. Form I, line 11, 122.17
line 16, 128.4

line 17, 125.28 is$=2u^d$

a quantity which enters into the formula to be described.

It is twice the deflection to either side of the magnetic meridian measured in divisions of the magnet scale. To determine the value of V, the effect which 90° of torsion in the suspending thread has upon the direction of the magnet, the following observation must be made:

The magnet being at rest, read and record the torsion circle at the top of the suspension tube, and read the scale of the magnet (line 19, Form I, 275° 40′, 80.2). Turn the torsion circle through

1 FORM I.—HORIZONTAL INTENSITY.

2 EXPERIMENTS OF DEFLECTION.

3 Station, Philadelphia. Date, June 11, 1865.

4 Mag. C. 6 deflecting. Mag. C. 17 suspended.

5 Observer, F. R.

	Mag-net.	North end.	Time. h.	m.	Temp t	Scale readings.		Alternate means.		Diff's.	Dist.
6											
7	West.	W.	10	30	70°	152.5	157.5	155.0		122.25	r=2.0 ft. log.=0.30103
8		E.				32.0	33.5	32.75	155.15		
9		W.				151.2	159.5	155.3	32.97	122.10	
10		E.				31.6	34.8	33.2			
11										122.17	
12	East.	E.				28.8	31.1	29.9	29.9	128.40	
13		W.				156.8	159.8	158.3			
14		E.				28.0	31.6	29.8	158.3	128.40	
15		W.	11	0	71°	157.0	159.5	158.2			
16										128.40	
17	Means.		10	45	70°.5				2^{ud}	125.28	

	Tors.	cir.	Scale.		Diff's.			Log's.
19	275°	40′	82.2	78.2	80.2		$\frac{125.28}{2}=62.64=u^d$	1.79685
						6.7		
20	365°	40′	88.3	85.5	86.9		$1^d = 2'.879$	0.45924
						13.9		
21	185°	40′	74.0	72.0	73.0		$1+\frac{H}{F}$	0.00160
						7.0		
22	275°	40′	82.5	77.5	80.0		181′.01... ....$=u$	2.25769
23			Mean=v=		6.9		=3° 1′.01..................	
24				Log's.			Log. of $r=0.30103$ Tan. u	8.72181
25	$v=19'.96$						3	
26	$5400'+v'$			3.73399			0.90309 r^3	0.90309
27	5400 (ar. co.)			6.27761			$\frac{1}{2}$	9.69897
28	$1+\frac{H}{F}$			0.00160			$.2108=\frac{m}{X}$	9.32387

90° the numbers increasing, viz., from 275° 40′ to 365° 40′ (275°40′+90°= 365° 40′), read scale and record, (line 20). Turn circle *back* 180° (viz. to 185° 40′) read and record (line 21) turn again to original position (line 22).

Take the differences and the mean will be the value of V in scale divisions.

The middle difference recorded (between lines 20 and 21), is due to 180° not to 90°, and we must therefore divide the sum of the differences 6.7+13.9+7.0 =27.6 by 4 to get the mean for 90°=6.9.

These scale divisions being arbitrary we must have their value in minutes of arc. This value is constant for the same magnet and same instrument, but if any changes are made, it must be re-determined.

To determine it, bring the magnet to rest, and turn the telescope until it points to a division near one end of the scale, clamp all fast and read the scale and the verniers of the theodolite, unclamp the upper screw of the theodolite and turn the telescope towards the other end of the scale, read scale and verniers. The number of minutes passed over by the theodolite, divided by the number of scale divisions passed over, will give the value of one scale division in minutes.

Example:

Theod. readings.	Scale readings.		
62° 55′	124.6	119.0	mean=121.8
67 34	28.1	21.7	" = 24.9
4° 39′=279′			diff. 96.9

$$\frac{279'}{96.9}=2'879=1 \text{ sc. div.}$$

The value of V (line 25, Form I) is got by multiplying 6.9 scale division by 2′.879 to bring it to minutes of arc.

It will be desirable to repeat these observations with the deflecting magnet at a different distance, as for instance, 1.5 feet instead of 2 feet, as in Form I, r=2 feet, so as to be able to combine the observations.

Now having the value of u^d in scale divisions (line 19, 62.64), we reduce it to minutes of arc, applying the small correction $1+\frac{H}{F}$ obtained from observations for torsion, line 28, getting a value of $u=3°1'.01$.

Now m, the magnetic moment of the magnet, is to X, the horizontal force of the earth, as 1 is to the tangent of u, multiplied by one-half the cube of the distance of the deflecting magnet, or $\frac{m}{x}=\tan.\ u\ \frac{r^3}{2}$, and, in Form I, performing this operation, we get $\frac{m}{x}=0.2108$ as the ratio of the magnetic moment of the magnet to the earth's force.

The tangent of u enters into this formula instead of the sine, because the deflecting magnet is at right angles to the magnetic meridian, and not to the magnet itself, when it is deflected.

13. An improved instrument, the Theodolite Magnetometer, is coming into use, in which the divided circle is under the magnet box, and the reading telescope is attached to the magnet box, as are the arms which carry the deflecting

magnet, so that the deflecting magnet is always at right angles to the axis of the suspended magnet when the telescope points to the axial division, and the amount of deflection is measured on the circle directly in degrees and minutes. As in this case we are no longer limited to the length of the scale in the magnet, the deflecting magnet may be used at short distances, and the deflection u increased to a considerable amount, say 15° to 18°, instead of 3° as in Form I, thus adding to the accuracy of the results.

The objection to the apparatus as a portable one is, that it cannot be made useful for general surveying purposes as can the theodolite of the instrument described, and where the means of transportation are limited, this is a matter of some importance.

As generally made, the Theodolite Magnetometer is not well adapted for determining declination, but an improved form designed by Mr. Hilgard, of the U. S. Coast Survey, is so arranged as to obviate that difficulty, and to give many other advantages over the old instruments.

A form (Form II) is given for observations and computations with this instrument. In the computations it will be observed that the *sine* of u, and not the tangent as before, is used.

Having now determined the ratio of m and X, we must get an expression for their product mX, this product being equal to $\frac{\pi^2 K}{T^2}$, $\pi^2 K$ being a constant determined by a method which will appear further on, and T being the time of a given number of vibrations of the magnet which has been used as a deflector, when swinging freely under the action of the earth alone.

14. OBSERVATIONS OF VIBRATION.

To determine T we take off the deflecting rod and change the magnets, putting that one which was used as the deflector, into the stirrup.

Bring the magnet to rest, and turn

the telescope until its vertical hair cuts the axial division of the scale.

By means of the magnetized screw-driver deflect the magnet about sixty minutes (in the case of the instrument recorded in Form I, about 20 scale divisions) to either side of the magnetic meridian and wait until it vibrates steadily.

Then enter the time as shown in Form III, lines 7, 8, 9, 10, &c., of the 10th, 20th, 30th, &c., passage of the central division over the wire, and again of the 200th, 210th, 220th, &c., up to 250 vibrations. Note the temperature at begining and end—the thermometer being in such a position that it will show the temperature of the magnet as nearly as possible, and the extreme scale readings, showing the amplitude of the vibrations as in columns 4 and 5.

In column 6 carry out the time of 200 vibrations, as deduced from the difference between 0 and 200. 10 and 210, &c.

Make observations for torsion and determine $1+\frac{H}{F}$, exactly as in Form I.

FORM II.—HORIZONTAL INTENSITY.

DEFLECTIONS WITH THEODOLITE MAGNETOMETER.

Station, Magnetic Shanty, Eastport, Me. Date, Jan. 15, 1860, P.M.
Mag. A deflecting at right angles to Mag. B suspended.
Distance $r=1.35$ ft. log.$=0.13033$.

Magnet.	North end.	Circle Readings.					Circle Readings.				
		No.	A		B	Mean.	No	A		B	Mean.
			°	'	'	'		°	'	'	'
East.	E.	1	63	15.5	15.0	15.25					
	W.						2	57	05.5	05.0	05.3
	E.	3	63	15.5	15.5	15.5					
	W.						4	57	05.7	05.5	05.6
	E.	5	63	15.0	15.0	15.5					
	Mean		63			15.2		57			05.4

			°	′				°	′		
West.	W.						6	57	06.0	06.0	06.0
	E.	7	63	11.0	11.0	11.0					
	W.						8	57	08 5	09.0	08.7
	E.	9	63	11.5	12.0	11.8					
	W.						10	57	07.0	07.5	07.3
	Mean		63			11.4		57			07.3

	°	′
Mag. E., $2u=$	6	09.7
Mag. W., $2u=$	6	04.1
Mean	6	06.9
$u=$	3	03.5

	Logarithms.
$\frac{1}{2}$	9.69897
r^3	0.39099
Sin. u	8.73515
$\frac{m}{X}$	8.82511

Beginning, Time 3h. 35 m., Temp. 34°.

Ending, Time 4h. 10 m., Temp. 35.5.

Observer, G. B. Vose.

Another observation, Jan. 16, with $r=1.80$ ft. gave $\frac{m}{X}=8.83156$.

Then for calculation, as in Form IV, enter the observed time of observations, apply the correction for rate of the chronometer used for observing, and thus get T′.

Enter the log of T′ in line 9, double it for T'^2, apply the correction for $1+\frac{H}{F}$ from Form III, and the temperature correction $1-(t'-t)\,q$, which is obtained as follows:

On the left hand side of the table, q (line 10) is a constant representing the change of magnetic moment of the magnet for one degree Fahr. of temperature, determined by the maker, or at a permanent observatory, and given with the instrument. (Riddell, page 89).*

---

* The temperature corrections may be determined by the observer, by using the deflecting magnet in its bar as in the observations for Form I, and noting the change of direction, caused by change of temperature, produced artificially.

They are usually very small, and owing to the difficulty of determining the exact temperature of the magnet, from the fact that it is never certain that the temperature of the surrounding air even close to the magnet itself is that of the magnet, and except in the very accurate observations of fixed observatories they may be neglected.

In the example given, this quantity is 0.0004. Then t being the temperature of the deflecting magnet in the observations of deflection which are to be used with these observations, and t' the temperature of the same magnet now suspended, the difference $(t-t')$, in this case 1°, is multiplied by the correction for 1°,q, (line 12, Form IV) and added to or subtracted from 1, according as it is positive or negative (— if t' is less than t, and + if it is greater).

Its log is then entered in the right hand column, and the log of T^2 found by adding logs in lines 11, 12, 13.

From previous investigations

$$mx=\frac{\pi^2 K}{T^2}. \quad \pi \text{ is } 3.14\,159.$$

K represents the moment of inertia of the magnet and its stirrup, the weight of which evidently modifies the time of vibrations.

K is determined by the formula

$$K=W\left(\frac{r_i^2+r_e^2}{2}\right)\frac{t^2}{t'^2-t^2}$$

FORM III.—HORIZONTAL INTENSITY.

EXPERIMENTS OF VIBRATION.

Station, M. E. X. Date,

Magnet F. Inertia Ring, None.

Chron. A. B., No. 165, rate 1s.75 losing on mean time

No. of vibrations.	Time.			Temp.	Extreme scale readings.		Time of 200 vibrations.	
	h.	m.	s.				m.	s.
0	2	06	13.2	71°	97.3	55.5		
10		07	24.1					
20		08	34.6					
30		09	45.6					
40		10	56.5					
50		12	67.5		91.1	63.7		
200		29	51.4				23	38.2
210		31	01.4					38.3
220		32	12.4					37.8
230		33	23.5					37.9
240		34	34.2					37.7
250		35	45.6	72°	86.1	68.8		38.1
	Means			71° [illegible]			[illegible]	[illegible]

Coefficient of torsion. Value of one scale div.$=2'.879$.

Tors. cir.	Scale.		Diff's.	
275° 40′	82.2	78.2	80.2	
				6.7
365° 40′	88.3	85.5	86.9	
				13.9
185° 40′	74.0	72.0	73.0	
				7.0
275° 40′	82.5	77.5	80.0	
Mean$=v=$				6.9

	Log's.
$v=19'.96$	
$5400'+v'$	3 . 7 3 3 9 9
5400 (ar. co.)	6 . 2 6 7 6 1
$1+\frac{H}{F}$	0 . 0 0 1 6 0

FORM III.—HORIZONTAL INTENSITY.

EXPERIMENTS OF VIBRATION.

Station, M. E. X. Date,

Magnet F. Inertia Ring, None.

Chron. A. B., No. 165, rate 1s.75 losing on mean time

No. of vibrations.	Time.			Temp.	Extreme scale readings.		Time of 200 vibrations.	
	h.	m.	s.				m.	s.
0	2	06	13.2	71°	97.3	55.5		
10		07	24.1					
20		08	34.6					
30		09	45.6					
40		10	56.5					
50		12	67.5		91.1	63.7		
200		29	51.4				23	38.2
210		31	01.4					38.3

20 Coefficient of torsion. Value of one scale div. $=2'.879$.

21	Tors. cir.	Scale.		Diff's.	
22	275° 40′	82.2	78.2	80.2	
					6.7
23	365° 40′	88.3	85.5	86.9	
					13.9
24	185° 40′	74.0	72.0	73.0	
					7.0
25	275° 40′	82.5	77.5	80.0	
26		Mean $=v=$			6.9

	Log's.
$v=19'.96$	
$5400'+v'$	3 . 7 3 3 9 9
5400 (ar. co.)	6 . 2 6 7 6 1
$1+\frac{H}{F}$	0 . 0 0 1 6 0

FORM IV.—HORIZONTAL INTENSITY.

CALCULATION.

$$T^2 = T'^2 \left(1 + \frac{H}{F}\right) \left(1 - (t' - t)\, q\right)$$

Observed time of 200 vibrations = $\overset{s.}{1418.00}$

Time of one vibration = 7.0900

Corr. for rate = + 0.0002

T′ = 7.0902

			Log's.
		T'	0.85064
q	0.00040		
$t'-t$	1°	T'^2	1.70128
$(t'-t)\,q$	0.00040	$1+\frac{H}{F}$	0.00160
$1-(t'-t)\,q$	0.99960	$1-(t'-t)\,q$	9.99983

15	$mX=\frac{\quad}{T^2}$	π^2K	2 . 2 1 8 6 5
16		mX	0 . 5 1 5 9 4
17		m	9 . 9 1 9 9 0
18		3.945=X	0 . 5 9 6 0 4
19	* Experiments of deflection. Date, June 11, 1865.		
20		$\frac{{}^*m}{X}$	9 . 3 2 3 8 7
21		mX	0 . 5 1 5 9 4
22		m^2	9 . 8 3 9 8 1
23	.8316	m	9 . 9 1 9 9 0

in which r_i and r_e are the internal and external diameters in inches of the brass inertia ring and W its weight in grains, t' the time of one vibration of the magnet with this ring and t without it at a certain temperature.

The log of π^2K is usually furnished to the observer with the instrument, but it may be obtained by a series of experiments with and without the inertia ring, the ring being carefully balanced on top of the magnet by aid of the wooden blocks which keep the magnet steady.

Subtracting the log of T^2 from that of π^2K we get the log of mX as in line 16.

Taking $\frac{m}{x}$ from the deflection experiments, referring to the date as in line 19, and adding its log and that of mX, we get the log of m^2 and consequently of m, and then (in line 18) the value of X.

15. INCLINATION OR DIP.

The instruments used to determine the inclination, are more simple in principle than those described, but the observations are not always so satisfactory, as mechanical difficulties of construction are apt to give trouble.

The dip circle consists essentially of a steel needle from six to ten inches in length, hung upon a small and accurately finished cylindrical axis, and carefully balanced on that axis so as to stand indifferently in any position. This needle is hung in the center of a vertical graduated circle, in some very delicate way, generally upon agate planes. The circle is mounted on levelling screws, and turns on a small horizontal circle at its base.

When this needle, which is somewhat lozenge shaped and has fine points, is magnetized and placed so that its axis is at right angles to the plane of the magnetic meridian, it will assume the position of the inclination, and the circle having been previously levelled by its foot screws so that the line joining its 90° marks is vertical, the reading of the point of the needle is the dip.

In order, however, to eliminate the errors which may arise from want of perfect balance of the needle, from want of symmetry of form, and from imperfect division of the circle, it is necessary to make observations in different positions and to take the mean of the readings as the result.

For instance to observe according to Form V. Enter station, date and numbers of circle, and of needle, lines 2 and 3, Form V. Each needle will be found to have one end marked, and we will begin with a needle the marked end of which has north polarity, that is the marked end will dip below the horizon when in the circle.

Place the circle upon the stand or on a firm table, level it by the foot screws, and raising the V supports of the axis by the handle provided for the purpose, hang the needle carefully in the V*s* by its axis, with its *marked side* towards you, lower it steadily until the axis rests on the agates, and then let the V*s* drop below out of the way.

If the needle rolls out of position, raise it with the V*s* gently and replace it.

Turn the circle by estimation at right angles to the magnetic meridian, and the needle will assume an approximately vertical position, turn the whole on its vertical axis until the upper point of the needle is exactly on 90°, record the reading of the vernier of the horizontal circle, then move the vernier of the horizontal circle if necessary, until the lower point of the needle is at 90°, turn the whole on the lower circle through 180° and repeat the reading of the upper and lower points.

The mean of these readings will be the reading of the lower circle when the needle is East and West, and at 90° from that reading the needle will be in the plane of the magnetic meridian.

Now, having the marked end dipping, the face of the circle, that is the graduated side, facing east, and the marked side of the needle facing east, enter the reading of the south or upper end in column S, line 8 (Form V), and of the lower end in column N, same line. Take out the needle and reverse it, turning the

1 FORM V.—MAGNETIC DIP.

2 Station, Date,
3 Dip Circle No. 13. Needle No. 2.

4 POLARITY OF MARKED END NORTH.

5	Circle East.				Circle West.			
6	Face East.		Face West.		Face East.		Face West.	
7	S.	N.	S.	N.	S.	N.	S	N.
	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
8	71 55	72 06	72 25	72 36	71 50	71 50	71 00	71 00
9	72 40	72 43	71 40	71 55	71 30	71 25	71 38	71 30
10	72 33	72 38	72 20	71 44	71 29	72 18	71 10	71 03
11	71 50	72 01	72 17	72 05	72 12	71 30	71 12	71 16
12	72 14.5	72 22	72 10.5	72 05	71 45.2	71 45.8	71 15	71 12.2
13	72 18.2		72 07.7		71 45.5		71 13.6	
14	72 12.9				71 29.5			
	71 51.2							

17	Circle East.				Circle West.			
18	Face West.		Face East.		Face West.		Face East.	
19	S.	N.	S.	N.	S.	N.	S.	N.
20 21 22 23	° ′	° ′	° ′	° ′ Read	° ′ ings.	° ′	° ′	° ′
24								
25								
26								
27				71	50.8			
28	Resulting Dip : mean of 71 51.2 and 71 50.8=71° 51′.							
29	Observer,							

marked face to the west, and read and record both ends, then reverse again and repeat the reading, twice, three or four times as may be considered necessary. It will be found that the needl will not come exactly to rest very soon and it is therefore better to read the d visions between which it vibrates and t take their mean as the reading, as it done in the deflection experiments.

In Form V, lines 8 and 9, and 10 an 11, these extreme divisions are recorde their mean being the point at which th needle would stand if it had time t come to rest, thus the mean 72 14.5 o the four readings is the same as the mea of the central reading of the two pair 8, 9 and 10, 11. This is the best metho of recording, except for an old observe who is very expert at taking out th means in his head.

Turn the circle 180°, face to the Wes and repeat the observations as shown i the right hand side of form V.

Take the mean as in lines 12, 13, 14 15. Now take the needle out, lay it up on the wooden block provided for the purpose, fasten it down with the brass clip and reverse its poles making the marked end now the south end.

To do this, place the needle in its block with its N. pole to your right, take the bar magnets which come with the apparatus, one in the right hand and the other in the left, that in the right hand with its north or marked end downwards, that in the left hand with its south end downwards; rest them on the needle near its center and draw them to the points, lift and replace them near the center and draw to the points again, repeating this movement half a dozen times. Turn the needle over with its other face up and rub in the same way.

The poles of the needle will then be reversed, that end which has been rubbed with the north end of the magnet having become the south pole.

This needle is then replaced in the circle which has been kept clamped in the plane of the magnetic meridian, and the second set of observations as recorded in the second part of Form V is made.

The final mean of both sets is the dip. Changing the magnetism of the needle eliminates any error that there might be in the mechanical balance of the needle. There is still a mechanical source of uncertainty from the irregularities of the pivots.

This is obviated by an arrangement suggested by Mr. Hilgard in which the pivots are so attached to the needle that they can be turned around and thus expose different sides to the agates. It is hardly necessary to say that great care must be taken that the pivots are not dirty or rusty, the magnets must be kept in their box with opposite poles at the same end and the soft iron keepers in their places. The needles must also be placed in their box with opposite poles at the same end. The small divisions on which they rest at each end are usually made of soft iron and thus serve as keepers.

16. The observations here described having been made and the results recorded they may be plotted upon a chart so

as to exhibit the relations between them clearly to the eye.

The observations of declination, (or variation) having been plotted in sufficient numbers a continuous line is drawn through all the points of no variation, another through those of one degree variation, etc., until the chart is filled up. These lines, which are called isogenic lines, or lines of equal variation, will be found to form curves which are extremely irregular in their form and distribution, but of which, those representing Westerly variations cover at this time the Atlantic, the Eastern portion of the United States and Europe and Africa with a small portion of Eastern Asia where they come in as closed curves.

The lines of Easterly variation form loops and closed curves in the center of the Pacific near the Equator.

These lines are laid down for every degree or for every five or ten degrees depending upon the scale of the chart; and the variation for any position between the lines can be obtained by interpolation.

Tables of the variation are given in the books on navigation (Bowditch's Navigator, Table LI). If the lines of equal dip are plotted it will be found that they are much more regular than those of equal variation, and that they approximate to the direction of parallels of latitude, the line of no dip being near the Equator.

This line is therefore sometimes called the magnetic equator. North of it, the north end of the needle points downwards, south of it south end.

The lines of equal horizontal force approximate also to the parallels of latitude, but not so nearly as those of equal dip.

The greatest horizontal force is near the Equator as should be the case even if the total force were everywhere constant, since as the dip decreases the horizontal component of the force must increase.

In addition to the obvious and simple use of these collections of observations to the navigator they form the basis of the whole discussion of the magnetic condition of the earth, and are therefore being considered with all the refinements of mathematical investigation with a view of deducing the general laws and permitting the computation in advance, of changes in the direction and intensity of the magnetic force.

An admirable article upon Terrestrial Magnetism by Prof. Joseph Lovering, of Cambridge, in the American Almanac for 1837, is recommended to those who wish a further acquaintance with the subject.

It is only necessary to suggest to the observer that observations made in places hitherto little examined are more useful than those made in well studied localities, and great care and attention should be bestowed upon such observations.

17. Before going to the second part of our subject it will be desirable to call attention to some properties of artificial magnets.

Although a magnet may be of any form, or rather although any piece of iron or steel may be magnetized, we shall for the present confine ourselves to the consideration of a rod or bar, remembering that what is called a horseshoe magnet is simply a bar so bent that its ends are brought near to each other.

A rod when magnetized, has its two ends converted into magnetic poles one of which points towards the north when the rod is freely suspended. This end is sometimes called the marked end, sometimes the *red* end and the other the unmarked, or the *blue* end, being thus distinguished in certain pieces of apparatus.

18. When an iron bar having no magnetism is brought very near to one pole of a magnet, a temporary state of magnetism of a character opposite to that of the pole is *induced* in it. If the end of the soft bar is brought near the north pole of the magnet it becomes temporarily a south pole. If a rod of hard iron or steel is so placed the magnetism induced becomes permanent.

Thus to magnetize a steel bar or to change its magnetism as in Sec. 15, it is touched, or for the purpose of getting more energetic action, rubbed with a magnet, that end which is rubbed with a north pole becoming the south pole of the new magnet, and *vice versa.*

19. Again a bar may be made magnetic by the action of galvanic currents upon it, as when it is placed in the center of a coil of wire through which currents from a battery are passing, the ends become poles, the bar permanently retaining its magnetism if it is of steel, but losing it if it is of iron, as soon as the current ceases or it is withdrawn from its influence. Upon the latter phenomenon is based the Morse telegraph.

Since currents are passing through and over the earth continually, a bar will be similarly magnetized by being placed in certain positions with reference to them, and it is found that a bar placed in the plane of the magnetic meridian, and the direction of the dip, or in other words, in the direction of the total force, will become a magnet, retaining its magnetism if of steel, and if of iron, losing it in proportion as it is moved into a position at right angles to the magnetic meridian when it returns to its inert condition.

This induced magnetism may be rendered stronger if while the bar is in position it is violently hammered or shaken. The magnetic distinction between soft and hard irons is based only upon their capacity to retain the magnetism imparted to them, and steel may be classed as a hard iron. If a magnet or compass needle is freely suspended and another magnet brought near to it, it will be found that the opposite poles attract each other and that the similar poles repel each other.

Thus if we approach the north, or marked end, of a bar magnet to the north end of the compass needle, that end of the needle will move away from the bar, while it will move towards the bar if it is reversed and the south end presented. This is true of temporary induced magnetism also, so that if one end of a bar of soft iron is presented to the north end of the needle that end of the bar immediately becomes a south pole by induction (18) and attracts the north end of the needle. If the *same* end of the soft bar is now presented to the south end of the needle, it becomes a north pole by induction and attracts the south end, so that soft iron attracts both ends of the needle unless some stronger action than that of the needle gives it for the time a particular magnetism.

With this short explanation of the action of magnets upon each other we will proceed to the consideration of the action of the compass on board ship.

MAGNETISM OF IRON VESSELS.

20. It has been supposed that the magnetic condition of certain rocks, well known as affecting the action of the needle when the compass is used on shore, would interfere with its action on the water, but although the compasses of a ship in a dock, surrounded by large masses of iron or moored in very close proximity to magnetic rocks, will be

affected, there is no reason to suppose that any rocks act upon the compass at the distance within which vessels ordinarily approach the shore.

A compass placed upon a ship built wholly of wood, would be subject only to the variations which we have considered, and they are now determined with sufficient accuracy to prevent any danger occurring from their interference; but in a vessel, in the construction of which iron is used to a greater or less degree, or in a steam vessel, there are disturbances of magnetic condition which are of the utmost importance.

21. In the first place, soft iron without any magnetism of its own affects the compass (19), since under certain conditions it becomes temporarily a magnet; while iron which has acquired any degree of magnetism either by position or by manipulation acts upon the needle in a still more powerful manner. If we balance a long needle in such a way that it may move freely in both a horizontal and a vertical plane, and then magnetize

it, it will turn into the vertical plane of the magnetic meridian, and will dip in that plane according to the magnetic latitude of the place of experiment, (16).

If we suspend a bar of soft iron in the same position it will immediately acquire magnetic force, which it will lose again in proportion as it is moved out of this position, (19). In consequence of this, iron in a vertical position frequently affects the compass to a great extent. In the case of U. S. Sloop of War, Ticonderoga, examined in 1863, the standing mizen rigging which was of iron wire, acted so powerfully and in such a varying manner upon the steering compass, which was in a line joining the mizen chains, that it was found necessary to remove it and substitute hemp rigging before the compass could be corrected in any satisfactory manner.

In fact all the deck beams and pieces of iron in a vessel become magnetic to a greater or less extent, and as they change a portion of their magnetism with changes of position, they act differently upon the compass as the ship heads in different directions; and as they slowly lose or gain, relatively or absolutely, their action changes also as time elapses.

22. As the effect on the compass in such cases is the resultant of the action of a large number of pieces of metal in different positions, the determination of this effect must always be a matter of experiment with each particular vessel and for each position on it; but the consideration of the action of certain masses in a few positions will lead to results that may enable the officer to select the position in the ship which will be most free from disturbances, and frequently to make such dispositions as may neutralize the peculiarly bad effects of certain arrangements.

It will also enable us to correct the compass empirically, by introducing disturbing causes which will nearly balance those arising from the material of the vessel.

23. We must be careful to distinguish clearly between variation and deviation.

The *variation* is the amount by which the compass points E or W of the true North, by reason of the want of coincidence of the magnetic pole with the pole of the earth (6) the *deviation* is the amount by which the compass deviates from the *magnetic* North and depends upon the ship's action and position.

24. In one sense we may consider an iron vessel as a magnet which acts upon the needle as the earth does, and the needle will in that case be acted upon by the combined forces of the earth and the ship, and will assume a position depending upon the mechanical resultant of those forces.

Thus if the ship is so magnetized that the north end of the needle is attracted toward the bow, and the ship is heading to the magnetic North*, the action of the ship and the earth being in the same direction, the needle will not be disturbed. If, now, the ship alters her course, so as to head East, the needle will be drawn by the earth's force toward the North, and, by the ship's force to the East, and must, therefore, assume a position between the North and East, depending upon the relative amount of the two forces.

---

* It will be understood that in this treatise, North always means Magnetic North, unless otherwise stated.

The amount by which the needle is drawn from the magnetic North is called the deviation, and in the case which we have supposed, this deviation will change with the azimuth of the ship's head, being zero when the head is to the North, and attaining a maximum when the head is toward the East or West.

It is this deviation that we wish to study, so as to be able to predict it, to allow for it, or to correct the compasses so as to eliminate it. The action of the ship upon the compass is not, however, so simple as above supposed.

25. The force of the ship is never exactly to the head, but in a direction making some angle with the axial line of the ship, and therefore, for convenience, we divide this force, as we do that of the earth, into two components at right

angles to each other, viz., the ship's *force to head*, and the ship's *force to starboard*, as *ab* and *ac*, Fig. 1, *ad* the resultant representing in direction and amount the ship's force.

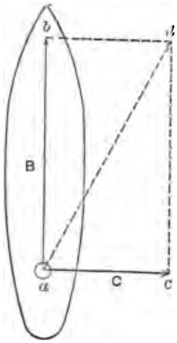


Fig. 1

We may also separate the *vertical* component of the ship's force but we shall not consider that at present.

26. To determine the amount and direction of the ship's horizontal force, any compass may be used, the needle of which traverses freely, but the more delicate the instrument the more satisfactory will be the results.

Place the compass in a position on shore free from any local attraction, and by means of a small magnet or a piece of iron deflect the needle 90° from the north point, permit it to vibrate and count the number of vibrations in a minute, repeating the observation several times to ensure accuracy. If the number of vibrations of the different sets do not agree within a quarter of a vibration either the instrument or the observer is at fault.

This number of vibrations in a minute gives a measure of the earth's horizontal force at the place. Then take the *same* compass on board the ship and count the number of vibrations in a minute made there. The ship's force with her head in the particular position at the time of the observation, and at the place occupied by the compass, will be to the earth's force as the square of the number of vibrations on board is to the square of the number on shore. A single observation on board will give a result, but it is much better to make a number with the ship heading in different directions, for the magnetism of the soft iron changes, as we have seen, with changes of direction.

To show how the amount and direction of the ship's force may be plotted and determined, we give an example at length, when the ship's force is greater than that of the earth, and the condition therefore somewhat exaggerated.

In this case the ship is represented by a rectangle of cast iron, which has become permanently magnetic, the compass being placed in the middle of it and one end of the rectangle marked as the bow.

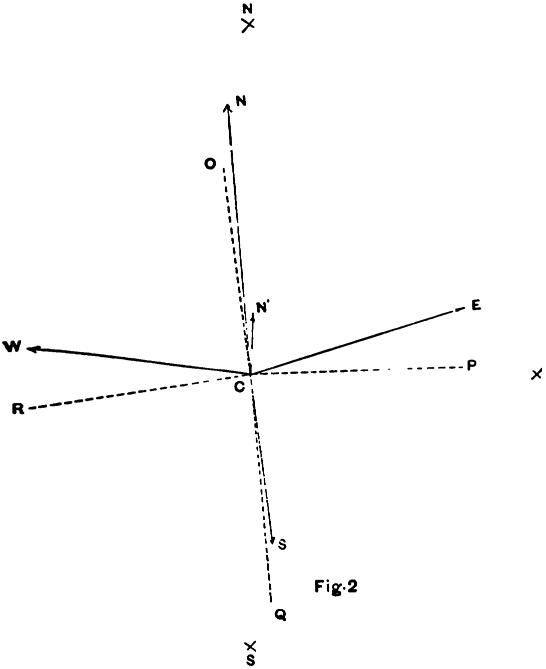
No. of vibrations on shore; that is not surrounded by the iron representing the ship, 9.5 in a minute. Bow to the North, No. of vibrations, 20.5; Needle pointing 6° W of N. Bow to the East, No. of vibrations, 18.75; Needle pt. 72° E of N. Bow to the South, No. of vibrations, 16.5; Needle pt. 7° E of S. Bow to the West, No. of vibrations, 18.40; Needle pt. 84° W of N. Now, as in these positions on board ship the needle is under the influence of the ship and the earth both, these directions and vibrations are due to the combined influence of earth and ship, and represent in direction and amount the resultant of the forces of earth and ship, and the forces are to each other as the squares of the number of vibrations, according to the law of the pendulum.

We have, therefore,

On shore,	$9.5^2 = 90.25$		
Head N,	$20.5^2 = 420.25$	Amount of resultant force	6° W of N
Head E,	$18.75^2 = 351.00$		72° E of N
Head S,	$16.5^2 = 272.25$		7° E of S
Head W,	$18.40^2 = 338.56$		84° W of N

Direction of resultant force.

We may now plot this so as to obtain the amount and direction (with reference to the ship) of the ship's force. In Fig. 2 let C be the position of the compass, the north being to the top of the page, CN′=90.25 representing in direction and amount the force of the earth, and C N =420.25 N 6° W, representing in direction and amount the resultant of earth and ship, the force exerted by the ship will, therefore, be represented by



Fig·2

CO=330, and 8° to Port of center line of ship.

So with head E, CE=351, N 72° E represents resultant of earth and ship, and CP the force of ship 335, 2° to Port of center line.

Again, with head S, C.S=272.5 S 7° E. and CO=368, 5° to Port of center line.

With head W, CW=338.56 N 84° W and CR=440, 9° to Port of center line.

Therefore, ship's force is $\frac{330+335+340}{3}$ =335 in amount as compared with earth's force, 90.25 or 3.71 earth's force being 1.00 and $\frac{8+9+2+5}{4}=6°$ to Port of center line in direction, the line passing through the position of the compass.

In taking the average of the amounts, the value to the S 368 is omitted, because the action of the earth and that of the ship being directly opposed, the needle is sluggish and its number of vibrations cannot be depended upon. This is an extreme case, since usually the ship's force is less than that of the earth, but it is selected because it shows the method better in plotting.

Of course, these values can be calculated by the ordinary means if greater accuracy is desired. It is obvious, also, that if only one or two observations can be made they are better with the head E or W than N or S.

It must be remembered that the direction and amount of the ship's force varies with her position within certain limits, and that one line can, therefore, only represent the mean force and direction.

Part of her force comes from her soft iron, and in this paragraph (26) we have considered that only her permanent magnetism is affecting the needle.

In Fig. 2, the line CE is the resultant (or diagonal of the parallelogram) of CN′ and CP; knowing CN′ and CE we construct the parallelogram CN′ EP and thus find CP which is required, and the same with CQ CR and CO.

Although the ship acts upon the compass as a whole, like a magnet; still it is not like a simple magnet, but one which changes its magnetism in different positions, and in fact its action is made up of the separate action of different parts.

27. The investigations of Poisson and Airy, show that part of the action of the ship is due to the permanent magnetism of the hard iron, and a part to the induced magnetism of the soft iron, (18) and the action upon the needle or the deviation can be expressed by a mathematical formula. The formula given by Poisson is more complete in some respects than that given by Airy, but the latter is simpler and is as follows:

$$S = A + B \sin. \zeta' + C \cos. \zeta' + D \sin. 2\zeta' + E \cos. 2\zeta'$$

in which S is the deviation to be determined.

ζ' is the azimuth of the ship's head by the disturbed compass, and A, B, C, D, E are coefficients whose values are determined by experiment.

Table I gives an analysis of these coefficients and should be carefully studied.

28. A is constant for the same ship

TABLE

$\delta = \mathbf{A} \cdot$

$\delta =$ *dei*

Constant: A
- Real: *from induction of* horizontal *force on* soft *iron unsymmetrically distributed.*
- Apparent: *from* index *or obs. error.*

Semi-circular *or* **Polar magnet.** *from*
- 1. *Permanent magnetism of* hard *iron, varying inversely as the* Horizontal force *at the place.*
- 2. *That induced by the* vertical *part of the earth's force on* soft *iron, varying as the* tangent *of the dip.*

B *is that part of this combined attraction acting in a* fore and aft *direction (the nat. sin. of B is* ship's force to head).

C *is that part of this combined attraction acting* athwart ship (*the nat. sin.* of *C is* ship's force to starboard).

The semi-circular deviati

As it depends upon the di

Quadrantal *sometimes called* **permanent** *coefficients, because* **unchanging** *in all magnetic latitudes.* *due to* horizontal *induction of* soft *iron in ship.*
- **D** *has four maxima at* intercardinal *points.*
- **E** *has four m* *points, and is ge* *it may be neglect*

The quadrantal deviation is diminish

and compass, and is real or apparent as shown in the table.

It is generally very small except in the case where the compass is not in the middle line of the ship. All these coefficients are positive (+) when they act towards the head or the starboard side, negative (—) when they act to the stern or to port.

29. B and C together represent a force which acts as represented in Fig. 1, and which has its zero when the ship's head s in a certain direction, (usually towards he North), and its maximum when the ead is at right angles to that direction, rom which peculiarity it is called the emicircular part of the deviation.

It is caused: I, by the permanent agnetism of the hard iron, and as that constant it varies inversely as the rth's horizontal force; II, by the inuced vertical part of the earth's force on ft iron, and therefore changes with agnetic latitude as the dip changes.

As this force rarely acts in the direction f the ship's length we divide it into

two, B, acting fore and aft, and C acti
athwart ships.

30. D and E represent a force whi
is due to the horizontal induction of s
iron, and which is called the quadran
part of the deviation, for the followi
reason.

If a bar of soft iron is held in t
direction of the dip it becomes a magn
the upper end of which, in North l
tude, attracts the N end of the magn
(21) if it is moved into a horizontal
sition, but still pointing North and So
it is still magnetic, under the influe
of the horizontal component of
earth's force though in a smaller degr
If it is now moved horizontally into
East and West position, its magneti
still further diminishes and when
reaches the East and West position
magnetism disappears altogether.

If, therefore, a compass is acted u
by this bar, when the bar is North
South of the needle, it attracts it stron
but as the needle is already point
North, its directive force (7) is increas

but its direction is not disturbed; if the bar is carried around radially, say to the East, the needle is drawn toward it and so has an Easterly deviation.

But the bar as it approaches the E and W position, loses its magnetism; and when E and W has none, and therefore does not attract the needle, and produces no deviation; consequently, the deviation will be zero when the bar is N and S and N of the compass, zero when the bar is E and W and E of the compass and will have a maximum somewhere between N and E.

It will be the same in each quadrant except that in the second quadrant E to S the S end of the needle will be attracted by the N end of the bar, thus giving a W deviation. E in the S to W quadrant and W again in the W to N quadrant. (See Fig. 3.)

The top of the page represents the North.

This quadrantal deviation is divided into two parts, D, which is the more important, and which has its maxima at or

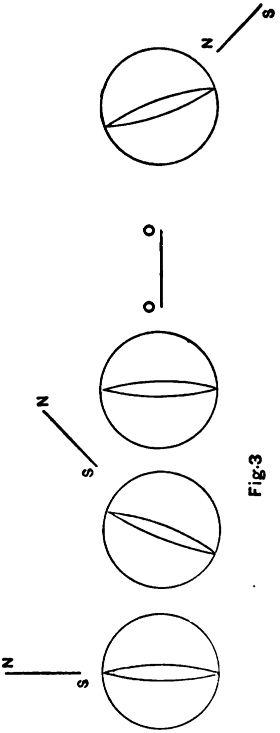


Fig.3

near the intercardinal points NE, SE, SW, NW and E which has its maxima at the cardinal points N, S, E, W, and which is generally so small that it may be neglected. It arises from soft iron unsymmetrically distributed.

31. Of the five coefficients, A and E are small, and B, C, and D are the important ones to consider, and those we shall therefore discuss at greater length.

A portion of the action which introduces the coefficients B and C is, as already noticed, due to the permanent magnetism of the hard iron composing the ship.

A piece of hard iron or steel may be made a permanent magnet by touch with another magnet, by subjection to the action of a current of artificial galvanism or by being placed in such a position that the currents of the earth will magnetize it.

The last is the only method by which a vessel will be magnetized, and as the currents of the earth have a definite relation in their direction to the earth itself, it is evident that the magnetism of iron vessel will vary with the positi which the ship has during its building, in the case of an iron clad, during i plating. Late investigations* have indicated that the North end of the needl is attracted toward that part of the ve sel which was nearly South in building.

That this magnetism is more constan in vessels built North and South than i those built East and West.

That the diminution of the directive force is greater if the ship has been built E and W, than if built N and S.

That the deviations in a ship built E and W are less symmetrical, regular and permanent than those on a ship built N and S. From which it is evident that it is better to build ships N and S, than E and W. When the compass is to be placed in the after part of the ship, as is the case with most of our war vessels, it is best to build the vessel head to the South, because if the ship is built head North the upper part of the stern, and the lower part of the bow, will be strongly magnetized, and the lower part of the stern, and the upper part of the bow weakly, so that a compass placed near the stern will have a large semicircular deviation.

---

* Evans and Smith, Phil. Trans. Pt. I, 1865.

If the compass is amid-ships the direction in building is not important, and if the compass is forward as in some merchant propellers, the head should be North in building.

32. The amount of magnetism upon which B and C depend is affected by the treatment which the vessel receives during building, and after being launched and in the early part of her service.

If in a vessel to be plated, built with the head North, a certain amount of magnetism is introduced by her position, another amount having an opposite effect upon B and C may be introduced by plating the vessel with her head South, and in this way the semicircular deviation of an after compass (31) may be much diminished, annulled or reversed by this operation, a fact of great importance, since although the position fo building cannot often be chosen—such a position for plating as will modify this element of the deviation, can almost always be selected by choosing one or the other side, or the end of a wharf, and mooring the vessel bow in or bow out.

No case has been reported, within the knowledge of the writer, in which the complete experiment has been made, but the observations on the Warrior, Black Prince, Defence, Resistance and Valiant (Evans and Smith, Phil., Trans. Pt. I 1865) where the directions before and after plating were different, have given just the results which might have been anticipated.

Again the permanent or subpermanent magnetism is affected by the jars or blows to which the iron may be subjected; thus if (19) a bar of iron held in the direction of the dip, be struck with a hammer it will become more highly magnetized than if it is held quietly; and shaking or pounding when in an E and W position will cause it to give up some of its charge.

For the first few months after launching, during which time the vessel is exposed to the hammering of the workmen in completing the work, to the vibrations of the machinery, and to the shocks of the waves, the values of B and C change, generally diminishing until they attain a permanent value in about one year.

Swinging at anchor through all azimuths, or merely lying quietly in a direction differing considerably from that of building, will also cause some changes.

It is evident that this magnetism is not exactly permanent, as that of a steel magnet is, and it is therefore sometimes called subpermanent.

33. It follows from these considerations that we may by judicious management, so modify the action of the hard iron, as in many cases to reduce the value of B and C to within small limits as far as they depend upon the permanent magnetism, and that this magnetism becomes settled or *shaken down* at the expiration of twelve months.

34. Now the intensity of the earth's

attraction of the needle to the North depends upon the magnetic latitude (16), and the ship's action being permanent in amount, the total directive force upon the needle will vary with the latitude, the effect of the ships becoming apparently greater as that of the earth becomes less, and B and C will therefore increase inversely as the horizontal force at the place, and will increase as the ship goes from the equator towards the poles.

35. There is another part of B and C (No. 2, Table 1), that induced by the vertical part of the earth's force on soft iron of the vessel, which varies as the tangent of the dip; that being the representative of the vertical part.

This can be separated from the first by treating observations made in different latitudes, or when the vessel is on an even keel and when she is heeled, as in the last case, the transverse iron, such as beams, posts, and the ship's sides, change their induced or temporary magnetism as they change their inclination.

The difficulties of heeling a vessel are however very considerable, and up to this time observations have not been made with sufficient differences of latitude to give very good results, so that 1 and 2 are not well separated.

The change of induced magnetism in the soft iron of the vessel is of great practical importance, however, in another respect, for when an iron sailing vessel or a steamer under sail, is careened by the wind, the deviation is sometimes much affected temporarily, and an error sometimes quite large, introduced, called the heeling error.

36. So far we have only considered the deviations while the ship is on an even keel, but they may vary when she heels to port or starboard, and as in some localities, a vessel may sail for days with the wind on the beam, this unexpected addition to the deviation may carry her out of the way.

The heeling error is produced by the action of the permanent magnetism, and by that of the induced magnetism of the transverse soft iron.

The direction of the ship's force is not necessarily horizontal, (25), in fact it is nearly always inclined more or less in the vertical plane. If it is of such a character as to draw the N end of the needle downwards, in the position of compass, it is said to act downwards, and it is evident that in this case, when the ship heels, the N end of the needle will be drawn to the weather side.

Again, the transverse iron such as deck beams, become magnetic as they incline, and their upper or weather ends attract the north point of the needle, thus further increasing the heeling error. If, however, the ship's force at the compass acts upwards, the needle is attracted by that to the lee side, and by the induction of the deck beams to the weather side, and thus the heeling error is reduced or practically destroyed. This is one strong argument in favor of building vessels head South in North latitudes, since such ships usually have an upward force in the after part where the steering compass is placed.

The effect of the induction will be changed at the magnetic equator, and will be reversed, as the upper end acquires magnetism south of the equator. Therefore, as far as this error is concerned, ships built to run in South magnetic latitudes, should be built head North.

This heeling error may be compensated on the same principle as the other deviation (46), by placing a vertical magnet in such a position, vertically under the compass, that it will produce no deviation when the ship is on an even keel and just enough of an opposite kind as the ship heels to counteract that produced by the ship itself. This will not be entirely satisfactory, since the error from induction in the soft iron will change with the latitude but it will reduce the error considerably.

Owing to the difficulty of heeling a vessel, there are not so many observations on this point as is desirable, and they should therefore be made whenever opportunity occurs. In all cases the angle of heel should be carefully determined and recorded with the results of the observations. In some vessels the error is very large, as in the City of Baltimore, 2° of deviation for each degree of heel. It is evident that as the heeling error due to the permanent magnetism is constant and that from induced magnetism varies with the magnetic latitude, observations of heeling error in the same ship and compass in different latitudes will enable us to determine the relative effects of the two, and such observations are very desirable, (35).

Vertical iron also produces a heeling error and in English iron merchant-men, where the steering compass is usually well aft, it has been found necessary to put up a vertical iron post forward of and below the compass to compensate for the effect of the stern post. Funnels, bulkheads, etc., frequently cause a heeling error.

The error is greatest in N and S courses, and least in E and W.

In compasses compensated by Airy's method with the magnets below the compass, the heeling error is much reduced.

Elaborate records of experiments in heeling vessels will be found in Appendix to Third report of Liverpool Compass Committee, 1862.

37. In considering the formula given in Section 27, it is evident that if we can get a sufficient number of equations with different values of δ and ζ' depending upon each other, we may determine the value of A, B, C, D and E.

This can be done in the following way: The ship being at anchor in a place where there is no current or moored in a basin where she is not in the immediate neighborhhood of large masses of iron or magnetic rocks, some distant object or objects must be selected, the correct bearing of which from the ship must be determined from the chart, or by careful observations *on shore* with an azimuth compass. The object must be distant, so that its bearing will not be sensibly changed by a small change in position of the vessel. (See Sec. 26 for other methods of determining deviation.) The standard compass must then be set up on board at a point in the *midship* line of the vessel which has been selected upon general considerations hereafter to be noticed (49), or after several observations of the kind now to be described.

In most vessels a position between the main and mizen mast will be found to be the best.

The vessel's head being brought to any cardinal point, say to the North, by the standard compass, the bearing of the distant object by this compass must be read off and entered opposite the heading of the vessel as in column II of Table II.

The difference between the true magnetic bearing of the distant object and its bearing by the compass will be the deviation, (δ) for that azimuth of the ship's head (ζ') and must be entered in 3rd column of the table on the first line. The ship's head must then be swung towards the East, either by warps or with the assistance of a steam tug or boats until her head is N *b* E by the standard compass, the bearing of the distant point is again noted, entered opposite N *b* E, and the deviation on that course deduced. The same observations must be made all around the compass, except that in entering them, it is convenient, as will be seen, to make a fourth column, and begin it with the readings at South as in Table II.

In practice it will not generally be found necessary to *stop* the ship at each of these points, as the observation can be made at the moment her head is in the right direction, provided she is not swung too fast.

It is also quite possible to make the observations in a tide-way, which is not too strong, by taking advantage of the ship's swinging with the tide, although difficulty will sometimes be experienced in making her go all around at the next turn, instead of back through the side of the circle in which the first half of the observations were made.

For instance, if with the first tide the ship swings from N to South by th East, in many tide-ways she will, without some extraneous aid applied at th right time, be apt to swing back to by the East, and not by the West.

A method (Napier's diagram) is give (42) by which observations made on an azimuths, not necessarily N, N *b* E, & can be used.

This table of deviations may be use in practice to steer by, since it shows th error of the compass on each course Thus in the case of the Calypso when the ship heads N by standard compass the needle points 6° 14′ to the W of Mag. N and the ship would be sailing more than half a point to the W of N so that a corresponding correction must be applied to enable a true N course to be steered.

38. To proceed to the computation o the coefficients A, B, C, D, and E.

It is shown in the English Admiralty Compass Manual (Evans and Smith) by a mathematical demonstration too long to be introduced here, that the values o

TABLE II.—RECORD OF DEVIATIONS AND COMPUTATION OF COEFFICENTS.

U. S. Steamer "Calypso," Acting Master, F. D. Stuart, August 17, 1865.

Upper half of col. V.	Lower half of col. V.	quantities in cols. XI, XII	with signs of XII changed	Multipliers.	Products of col. XIV by multipliers.	Multipliers.	Products of col. XIV by multipliers.
		Const'nt part of deviation.	Quadrantal deviation.				
+ 0° 12′	+ 0° 11′	+ 0° 12′	0° 00′	0	0° 00′	1	0° 00′
+ 1 00	− 0 34	+ 0 13	+ 0 47	S_2	+ 0 18	S_6	+ 0 43
+ 2 26	− 1 55	+ 0 15	+ 2 10	S_4	+ 1 32	S_4	+ 1 32
+ 2 41	− 2 55	− 0 07	+ 2 48	S_6	+ 2 35	S_2	+ 1 04
+ 3 20	− 2 37	+ 0 21	+ 2 58	1	+ 2 58	0	0 00
+ 3 10	− 3 00	+ 0 05	+ 3 05	S_6	+ 2 51	$-S_2$	− 1 11
+ 2 03	− 2 08	− 0 02	+ 2 05	S_4	+ 1 28	$-S_4$	− 1 28
+ 0 25	− 1 21	− 0 28	+ 0 53	S_2	+ 0 20	$-S_6$	− 0 49
Sum of + terms =		+ 1 06	Sum of + terms =		+ 12 02		+ 3 19
" − " =		− 0 37	" − " =		− 0 00		− 3 28
	divided by 8)	+ 0 29		divided by 4)	+ 12 02		4) − 09
	A =	+ 0° 03.′6		D =	+ 3° 00′	E =	− 0° 02′

these coefficients may be deduced from the thirty two equations, giving the value of S by performing the operations indicated in the form given on page 554.

Prepare a form according to this example, the permanent part of which is indicated by the Roman letters and figures, and the quantities to be entered by the heavy faced type.

Enter in the second and fourth columns the deviations as observed on each point, giving Westerly deviations this sign— and Easterly ones the sign +.

Form column V by entering the algebraic sums of figures in columns II and IV, having reference to the signs, and dividing by two; and form column VI by adding figures in cols. II and IV the signs of quantities in col. IV being changed, and dividing by two.

It will be seen upon reflection, and especially if the figures in these columns are plotted (see page 96) so as to aid the mind in comprehending these, that the figures in the sixth column are the means of the deviations in the semicircles from

N to S, by the East, and from N to S, by the West, and represent therefore the mean semicircular deviations, and that those in column five represent the excess of the greater quantities over the mean, and represent therefore the quantities which affect the deviations, apart from the semicircular deviations, namely, the quadrantal deviations. On page 96 these are plotted, lines II and IV representing columns II and IV, and line VI the mean semicircular deviation.

Line V crosses the center line twice between N and S, and represents the quadrantal part of the deviation, line VI crosses once and represents the semicircular part.

If there were no quadrantal deviation lines II and IV would be nearly regular and symmetrical curves, equal on both sides of the axis, but the effect of the quadrantal deviation is to add to the semicircular deviation on the side towards which it acts, and to diminish it on the other side. For example, the mean deviation, Fig. 4, at N (or S) is—6°57′

(long dotted line VI), but II is drawn towards the plus side to a reading of −6°45′ and IV is pushed to the same side to a reading of −[illegible]. The difference between these readings, −0°24′ represents twice the action of the quadrantal deviation and $\frac{-0°24'}{2} = -0°12'$ represents the quadrantal deviation at N (or S).

The reader can make this still clearer by plotting from a center line, any regular semicircular deviation, and any regular quadrantal deviation, and then plotting the resulting deviation curve (Fig. 5), an operation the converse of the above.

In Fig. 4 the line VI is the mean of the two lines II and IV, IV having been turned over on to the same side of the axis as II, or having its *signs changed* (Col. VI).

38. Having thus separated the semicircular and quadrantal deviations, we proceed to compute B by multiplying each number representing the deviation

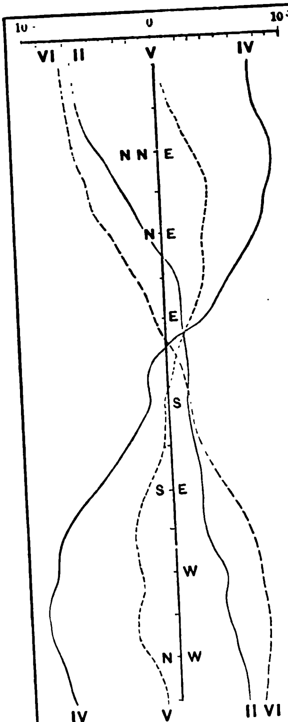


Fig.4

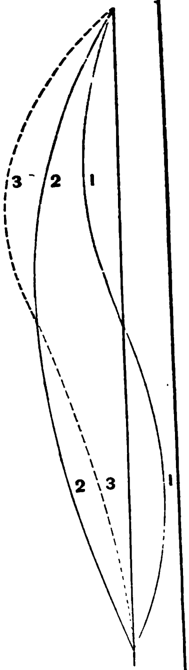


Fig.5

in Col. VI by the natural sine of the rumb of the course counting from the North, that is by O, S_1, S_2, &c., which are taken from the following table :

S_1=nat. sin. 11° 15′=.19509 1 point.
S_2= “ “ 22 30 =.38268 2 points.
S_3= “ “ 33 45 =.55557 3 “
S_4= “ “ 45 00 =.70710 4 “
S_5= “ “ 56 15 =.83147 5 “
S_6= “ “ 67 30 =.92388 6 “
S_7= “ “ 78 45 =.98078 7 “

In the English Admiralty Compass Manual, a table is given of the products of S_1, S_2, &c., with arcs up to 35°, which facilitates the operations very much.

These values are entered in column VIII.

The sums of the + terms, and of the — terms in this column are then taken and their difference with its proper sign + or —, divided by 8 gives the value of B in arc, as in the example $B = +1^\circ 43'$. We then form column X by multiplying the same quantities by the nat. sines of the rumbs, counting from E or W, to get C, which acts at right angles to B, the quantities S_1, S_2, &c., being entered in the inverse order.

The algebraic sum of the quantities in X divided by 8 gives the value of C, in example, $C=-7° 15'$.

Then to obtain the values of D and E, the quadrantal coefficients, we take column V and entering the quantities in the upper half in column XI, and those in the lower half in column XII, since we wish to get the mean of the quadrantal deviation, we perform in columns XIII and XIV, the same operations as in colums V and VI, eliminating the constant or index error A, and getting quantities in column XIV to be multiplied by S_2, S_4, S_6, etc., computing D and E as shown in columns XVI and XVIII. In the example $A=+0° 03'6$ $D=+3°00'$ $E=-0°02'$.

In case the observations are made on 16, instead of 32 points, that is at N., N.N.E., N.E. etc., the columns will be only half as long, and the divisions for B C and A will be 4, and for D and E, instead of 8 and 4, but the resulting values of the coefficients will not be so exact. Observations on 8 points will give less reliable values and observations on the four cardinal points will not give a value of D nor those on the quadrantal points, a value of E.

As D is more important than E, if observations on four points only should be possible in any case, they should be made on the quadrantal points.

It is obvious that having the values of the coefficients we may compute the deviations on any course to half or quarter points by substituting in each equation the azimuth of the course for ζ'.

40. These coefficients are, strictly speaking, only approximately correct, the more accurate values being expressed by $\mathfrak{A}, \mathfrak{B}, \mathfrak{C}, \mathfrak{D}, \mathfrak{E}$, which are attained as follows:

$$\mathfrak{A} = \text{sin. } A$$

$$\mathfrak{B} = \text{sin. } B\left[1 + \tfrac{1}{2}\text{ sin. } D + \tfrac{1}{12}\text{ver. sin.} B - \tfrac{1}{4}\text{ ver. sin. } C\right] + \tfrac{1}{2}\text{ sin. } C \text{ sin } E$$

$$\mathfrak{C} = \text{sin. } C\left[1 - \tfrac{1}{2}\text{sin. } D + \tfrac{1}{12}\text{ver.sin. } C - \tfrac{1}{4}\text{ ver. sin. } B\right] + \tfrac{1}{2}\text{sin.} B \text{ sin. } E$$

$$\mathfrak{D} = \text{sin. } D\left[1 + \tfrac{1}{8}\text{ver.sin.} D\right]$$

$$\mathfrak{E} = \text{sin. } E$$

For all ordinary purposes, however, the values represented by A, B, C, D, and E are sufficiently close.

41. The deviations may be observed by other methods than that of swinging the ship on known bearings. If in dock, or in a confined harbor, a compass carried around the ship on shore, by an observer who keeps always in a line with the masts will, at each moment, give the true magnetic bearing of the head of the ship; and she can be stopped on any desired point, or observations of her compass be made as she reaches each point in succession, by means of signals agreed upon by those on shore and on board.

Or the shore compass being kept in one spot, reciprocal bearings of the shore compass, and the ship's compass, can be made in each position of the ship which will agree if there is no deviation, and will differ by the amount of deviation on each course. In using this method, it has been suggested that the readings in each case should be chalked upon a blackboard to be seen by the opposite observers, in order that they may be certain that the readings and records are correct, before making each new observation.

In the case where the standard compass, having been placed in a carefully selected position (49), is perfectly corrected, it will be used as the ship swings to determine the deviations of the other compasses in their different positions on board.

42. The deviations in different courses may be plotted by laying down a straight line to represent no deviation and dividing it equally into thirty-two divisions, representing the points beginning at N at the top, and ending with N at the bottom, (Fig. 4). The amount of deviation on any given course may then be represented by laying off a distance to any convenient scale, equal to the amount of deviation opposite to the point representing the course, and to the right or left as the deviation is E or W.

By laying off a number of these for different courses, and joining the points

thus obtained, we shall have a
deviations which addresses
eye.

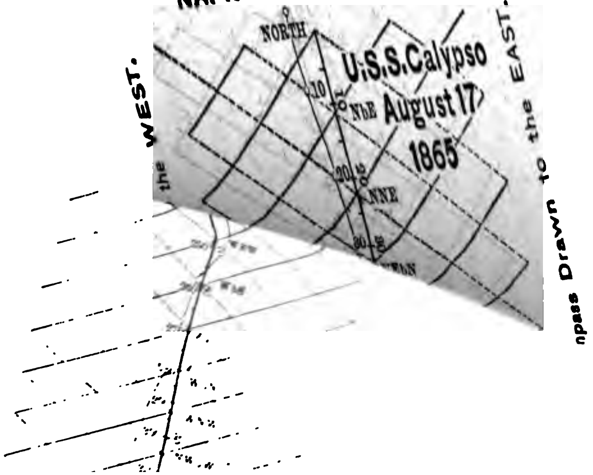
In order to do this in
will make a diagram of th
vice, Mr. Napier, of Glasg
what is known as Napie
in which the ordinates, on w
viations are laid off, are not
gles to the central line, but a
60° in each direction, making a
isosceles triangles, and conve
diagram into a simple addition a
traction table.

The central line is divided i
grees and serves as a scale by wh
deviations are laid off.

To use it, observe the deviat
any course, and lay off the am
that deviation on the line
through the course, on the plain
the course is correct magnetic,
dotted line if it be the disturbe
pass.

If this course is not exactly on
lay off the deviation on a line par

NAPIERS CURVE Fig.6



that passing through the nearest point as A. Having plotted in this way all the observed deviations, a curve is to be traced through them with a free hand, and the deviations on courses not observed upon are given by the intersection of this curve with the dotted or plain lines corresponding to each point.

The examination of a collection of curves, made from actual observations, as in the report of the Liverpool Compass Committee, &c., will show that there is so much regularity that these interpolated deviations may generally be relied upon, although certain cases, such as the U. S.S. Roanoke (Report of National Academy of Sciences for 1863) the irregularities are considerable.

There are two principal practical applications of this diagram.

I. From a given course by compass, which has been steered, to lay down the direct magnetic course which the ship has made.

Find the compass course on the central line. Move the pencil along the dotted line, passing through this course, or in a direction parallel to the *dotted* line, if there is not one passing through the course, until the curve is reached, then return in a direction parallel to a plain line until the pencil reaches the central line, the point thus reached is the correct magnetic course.

It will be observed that this is merely the addition or subtraction, as the curve is to the right or left of the center line of the deviation on this course, since the three sides of the triangle A, B, C, passed over by the pencil are all equal.

II. From a given correct magnetic course to find the course that must be steered by compass in order that the ship may follow the given course.

Find the correct magnetic course on the central line. Move the pencil in a line parallel to the *plain* lines, until it reaches the curve, and back parallel to the dotted lines to the central line, and the point thus reached is the course which must be steered. This is evidently the converse of the preceding operation, and consists in subtracting the deviation which before was added or *vice versa.*

The following verses are given in the English Admiralty Manual to aid the memory.

I.

"From compass course, magnetic course to gain
Depart by dotted and return by plain.

II.

"But if you wish to steer a course allotted,
Take plain from chart and keep her head on dotted."

43. Having determined the deviations on the correct magnetic courses, it will be very easy to construct a table giving the course to be steered by compass, in order to shape any desired course. It may have the following form:

STEERING TABLE. BINNACLE COMPASS, &c., &c.

Course to be made.	Course to be steered by compass.
N	N 8° W or N ¾ W nearly.
N by E	N 2½° E or N ¼ E "
N N E	N 13° E or N by E ¼ E "
N E by N	N 23° E or N N E "
N E	N 33° E or N E by N "
N E by E	N 43° E or N E ¼ N "
E N E	N 52° E or N E ½ E "
E by N	N 61° E or E N E ½ N "
&c.	&c.
&c.	&c.

44. As a table of deviations is troublesome to use, and as errors may be made in applying the correction indicated by the table, it is convenient to make a corrected compass card to steer by.

This may be done in several ways, first: by determining the deviation by swinging, and interpolating these points not observed on from Napier's curve, and then making a card to be put on top of the regular compass card, so distorted that the deviation will be allowed for by steering the ship by the new card. Thus, if the deviation when heading E true magnetic, is one point to the E, the west point of the new card must be one point to the left of the E point of the old card or over the point E by N, and so on all around so that the divisions of the card will not be equal, 11°¼ to a point, but will be greater or less as the deviation is greater or less in each position. If on N courses there is no deviation the N points of the old and new cards will coincide.

Instead of covering up the old card with the new one, the new points may be marked in red ink on the margin of the card outside of the regular division. (See Towson's Practical Information for Figure, page 29).

In the form of deviation card, devised by Com. Rodgers, U. S. N., the proper magnetic points are drawn on the outside of the compass, and with the arrow heads indicating them pointing towards the center to distinguish them from the old points.

45. A method of plotting the action of the ship on the needle from values of $\mathfrak{A}$, $\mathfrak{B}$, $\mathfrak{C}$, $\mathfrak{D}$, $\mathfrak{E}$, and $\mathfrak{F}$, too elaborate to be inserted here, is given in the Admiralty Compass Manual, under the head of Dygogram, Nos. 1 and 2.

These drawings give the means of studying the action of the various coefficients, and No. 2 may be used as a steering card.

46. It is possible to correct mechanically the compass of an iron vessel in such a manner that the deviations on all courses may be very much reduced, or even destroyed altogether.

Neglecting for the present, the vertical component (25), the action of the ship on the needle may be represented by that of a large magnet N S Fig. 7, or still further resolved into the action of two magnets S′N′, and S″N″ at right angles to each other, one in the midship line, the other athwart-ship. The action of the first may be corrected by a small gnet N^2S^2, placed fore and aft, and r to the compass with poles opposite hose of $N'S'$ and the action of the ond by a small magnet N^3S^3 athwart-

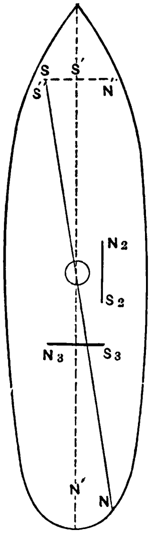


Fig. 7

with poles also opposite to those of ″. In practice this is done by plac- the vessel head N, and laying the magnet N^3S^3 upon the deck, either forward or aft of the compass, turning it end for end or moving it backwards or forwards until the needle points N when $S'N'$ is corrected. Then heading the vessel to the E or W, the magnet N^3S^3 is placed by trial in such a position that it makes the needle point N when $N'S'$ is corrected.

The magnets are then secured by letting them into the deck and nailing pieces of sheet copper over them.

If the magnetic axis of the vessel coincides with its midship line, no athwart ship magnet N^3S^3 will be required, and it is evident also that if the direction of NS is known, only one magnet N^4S^4, *parallel to it* need be used, but as in practical work this is rarely known the two magnets are used.*

The semi-circular deviation due to the permanent magnetism is thus disposed of, and the quadrantal (30) must be corrected by soft iron placed in a position to counteract the action of the soft iron of the ship. This may be done by having two small boxes, called chain boxes fixed one on each side of the compass, to starboard and port, into which soft iron chain, or pieces of annealed wire or iron are put in sufficient quantity by trial to make the compass point to the N correctly, when the ship's head is N E. S E. S W. or N W., the correction by the magnets having previously been made. The Liverpool Compass Committee use soft cast iron cylinders with hemispherical ends for the same purpose instead of chain, fixing them to port and starboard of the compass, and moving them farther or nearer to produce the desired effect.

---

* This method of correction by permanent magnets is known as Airy's method, it having been proposed by the Astronomer Royal of England.

This soft iron thus applied corrects D. E which is due to soft iron unsymmetrically distributed, may be corrected by moving the soft iron either backwards or forwards, but it is usually very small and may be neglected. The magnets used for compensating should be of good steel, made very hard and well magnetized sometime (some months if possible) before being used, so as to acquire a permanent condition of magnetism. They may be from fourteen inches to two feet in length and about ¼ in. by 1½ in. cross section.

It frequently happens that one correction will interfere with one already made, and it is therefore necessary to repeat the adjustments, with the head in different positions, so as to eliminate the errors, or if any obstinately remain, they must be averaged on the different courses, and noted in the deviation-table or on the card.

In other words, the compasses may not be *perfectly* corrected, but the deviations will be much reduced, and may be allowed for or not according to the judgment of the officer.

The heeling error may be compensated by a vertical magnet (36).

Experiments, for instruction and practice, on the action of the iron in a vessel and the method of correction may be readily made on shore or on board ship in a harbor, by arranging a table capable of being rotated around a centre, to represent the ship, and placing upon it permanent magnets and pieces of soft iron in different positions, to represent the iron of the vessel, a pocket-compass or a small prismatic compass being used as the ship's compass. For instance, in Fig. 7, N S may be a steel wire or rod magnetized and fastened to the table, the compass placed on the middle of this, supported on a couple of books, will show the semicircular deviation as the table is turned into various azimuths.

This may be then corrected by the use of two small steel magnets N^2 S^2 and N^3 S^3 placed by trial in the proper positions.

The soft iron may be represented by pieces of iron rod a few inches long and a quarter of an inch in diameter, which have been heated to a bright red and allowed to cool with the fire or cooled in sand slowly. These may be fixed vertically, horizontally, or inclined, and their action in different azimuths noted.

All the phenomena which occur on iron vessels may thus be studied with great ease, and the practice serves to familiarize the navigator with the effects which he will meet in practice, and enable him frequently to refer them to the proper cause.

47. The relative advantages of corrected and uncorrected compasses, the latter to be used with a deviation card, table or diagram, have been frequently discussed.

In the English navy, the compasses being usually uncorrected while in the English merchant service, Airy's Method is generally employed. Nearly all the iron blockade-runners captured during the rebellion, had permanent magnets, which were generally torn up by the captains before capture, with a view to make the navigation difficult to the captors.

Most of the iron and many of the wooden steamers of the United States navy have their compasses mechanically corrected.

It has been urged that the permanent magnets may lose their force, and thus introduce an error, which being unexpected might be serious, but as Mr. Towson remarks, no instance has yet been reported in which the magnets lost their charge more rapidly than the ship lost its magnetism. The heeling error, which can hardly be allowed for in practice by the use of a table, and which is sometimes very large, is much reduced by the compensation, and the effects of rolling on the needle are also much diminished.

As the deviation due to the permanent magnetism depends upon the relation between that and the earth's force, in an uncompensated compass it will change with change of magnetic latitude, and a table must be made for new positions.

Altogether the evidence seems to be strongly in favor of compensation, and in fact some of the recently-built English war-vessels have been obliged to come to it, owing to their very large deviations.

The vigilance of the commander must not, however, be relaxed because the compasses are supposed to be corrected, but every opportunity should be embraced to determine whether they have undergone any change.

It is no doubt very desirable to have an uncompensated compass fixed in the best part of the ship (49) to refer to from time to time. If the position selected is one which cannot be constantly occupied by this compass, it may be so arranged that it can at any time be replaced accurately in position by means of marks on the deck.

48. In order that a compass may be good, the needle should be very hard and well magnetized so as to retain its power, the cap should be of ruby or agate, carefully hollowed so as to be even and smooth, and the point should be hard, fine and sharp.

No dirt or dust should be permitted to get into the cap, as it will make the needle sluggish, and enable the point to grind into the cap. The point should be examined from time to time and kept sharp. It is important also that the point should be exactly in the intersection of the two diameters passing through the gimbals, and that it should be exactly at the same height as the centres of the gimbals, a matter frequently neglected by the maker. It has been shown that a compass is more steady, and that the quadrantal correction is more perfect when the card has two parallel needles, the ends of which intersect the circumference of the card at points 60° apart. The Admiralty compass has four needles.

If the bowl is of copper, or better if a stout copper ring surrounds the card, the vibrations of the needle will be calmed, that is their amplitude will be reduced, while the time of vibration will remain the same, owing to an action being set up which appears to be due to currents generated by the relative motion of the needle and the copper. It may be suggested that no means of *cutting off* the action of the ship's iron from the compass can be effectual, since anything which will do that will also cut off the action of the earth's magnetism also, and render the compass useless.

Owing to the peculiar difficulties experienced in finding proper positions for standard compasses on the Monitors, and to the necessity for having the steering compass in or over the steering turret and, therefore, in a position to be affected by the iron of the turret and of the large guns, particularly troublesome because they change their positions with reference to the other iron of the ship when they turn, several methods have been suggested by which the compass could be raised far enough above the turret to be free from the action of the ship and still to be available for the purpose of steering.

Ritchie's Monitor Compass, the first one suggested for this purpose consists essentially of a needle which works in a copper globe supported at a height of six or seven feet above the turret. This needle is attached to and turns with a delicate vertical axis which is long enough to go down through the top of the steering turret, and which carries on its lower end the compass card, so that when the needle above turns in obedience to the earth's magnetic force the card below turns with it and can be consulted by the steersman. In order to prevent friction on its bearing, and strains on the rod, the whole floats in a liquid the specific gravity of which is the same as that of the rod and its floats and card.

A description of its details which are very ingenious will be found in report of Nat. Acad. of Sciences for 1863.

Mr. Schott, of the Coast Survey, has suggested a compass with the under side of the card divided, like a tell-tale compass placed in a copper globe or box above the turret, and read by means of a mirror placed underneath it, with the aid of a glass if necessary, thus dispensing with the vertical axis and simplifying the apparatus.

Report Nat. Acad. Sc., 1863.

Mr. Hilgard, of the Coast Survey, has

devised a Magic Lantern Compass, in which the needle raised as before carries a transparent card of glass or mica, an image of which, by a proper arrangement of lenses, is thrown upon a table in the dark steering turret in front of the steersman. The light comes from the sky in daytime, and from a lamp at night. In this form a very short needle with its accompanying advantages, may be used.

49. The ship's standard compass, which should be an azimuth compass, should be placed in a selected position in the midship line where the deviations are the smallest and most regular. In wooden steamers, although there may be large deviations at the steering compass, it will usually be possible to find some place where the needle is not disturbed, but in iron vessels this can hardly ever be the case.

It is, perhaps, desirable that the standard compass should not be mechanically compensated, and if it is not, a table and curve of deviation must be prepared for it and every opportunity taken to verify it when the magnetic latitude is much changed. If upon calculating the coefficients (38) for the standard compass a large + D is observed, it may be reduced by placing the compass over a hatchway or a sky light, where the transverse deck beams being divided will act as two pieces of soft iron athwart ships, and thus partially correct the quadrantal deviation.

50. The magnetic condition of parts of a ship can be determined by bringing a small needle near to the part to be examined. If the N end of the needle is attracted, the part is said to have S polarity, and vice versa.

It will be found in examining iron ships, that they have almost, without exception, N polarity at one end and S at the other, and that the line dividing the different kinds, or the line of no polarity, runs obliquely from the bilge to the rail on either side, or that the surface of no deviation coincides more or less closely with a plane passing through the vessel obliquely. Observations on polarity a important, as indicating in many case the action which the vessel may be expected to have upon the compass.

51. The instruments required for investigations in the ship's magnetism are, 1. A good azimuth compass. 2. The ordinary ship's compass. 3. Boat compasses, which are very convenient for moving about. 4. The ordinary prismatic compass (Schmalkelder's). 5. A small pocket-compass for testing polarity (50). 6. A needle delicately suspended for vibration experiments. (The prismatic compass, if a fine one, will do for this purpose.) 7. A needle balanced so as to hang in the dip, very delicately hung on points or in jewelled holes for vertical vibration experiments. 8. Two or three small magnets, a small level, and a clinometer of some kind, to determine the angle of keel.

52. The most important books and articles on the subject of the magnetism of iron vessels are as follows:

"Admiralty Manual, for ascertaining

and applying the deviation of the compass caused by the iron in a ship by F. J. Evans and Archibald Smith, London: Potter, 1874. 4s. 6d. 8vo, pp. 199, plates." Fourth Edition.

"First and Second Reports of Liverpool Compass Committee. London, 1857. Small folio, pp. 74, plates."

"Third Report of Liverpool Compass Committee. London, 1862. Small fol., pp. 131, plates; 8 shillings."

"Practical Information on the Deviations of the Compass for the use of Masters and Mates of Iron Ships. By Thomas Towson, Esq. London: Potter, 1863. 8vo, pp. 122; 3 shillings."

"Paper by Edw. J. Johnson, Commander R. N., on Magnetic Experiments on an Iron Vessel, in Philosophical Trans. Part II., 1836."

"Papers by Geo. B. Airy, Astr. Royal in Phil. Trans. 1839. p. 167–213, 1856. Part I., p. 53–99. Athanaeum Ap., 1865."

"Paper by Mr. Evans, R. N., in Phil. Trans. 1860. Part II., p. 337–378, and in Jour. Royal United Service Inst. Vol. IX., pp. 22."

"Papers by Evans and Smith, Phil., Trans., 1861, Pt. I, p. 161–181. Phil. Trans. 1865, Pt. I, p. 263–323."

"Report of Compass Committee in Report of Nat. Acad. of Sciences to Congress for 1863."

"Magnetism of Ships and the Mariners' Compass. William Walker, Com'd R. N. London, 1853. 18mo, pp. 207."

"De la Déviation des Compas. E. Dubois. Paris, N. D. 18mo, pp. 56."

"Magnetism of Ships and Deviations of the Compass. A series of papers by various authors. Reprinted by order of the Secretary of the Navy, under the direction of Com. Jenkins, U. S. N. Washington, 1867."

"Smithsonian Contributions, No. 239, Magnetic Observations on U.S.S. 'Monadnock,' by Prof. Wm. Harkness, U.S.N. Washington, 1872.

The principal investigators in this especial subject have been Capt. Flinders, 1801–1803, Dr. Scoresby, 1819, and later, Major Gen. Sabine, Royal Artillery, Dr. Young, Mr. Barlow, Mr. Poisson, Mr.

Airy, Comd. Evans, Mr. Archibald Smith, Capt. Johnson, Mr. Rundell, Mr. Towson, Prof. Wm. Harkness.

In France it does not appear to have attracted the attention of scientific men to so great an extent, and in this country owing to the small number of iron vessels built before the war, it is only within the last few years that it has begun to receive the attention which its importance demands.

It is just now advanced to that point where every officer commanding, or on board of an iron vessel, may add his share to perfecting the general knowledge of the subject, by well devised and carefully executed experiments and observations.

⁂ *Any book in this Catalogue sent free by mail on receipt of price.*

VALUABLE
SCIENTIFIC BOOKS,

PUBLISHED BY

D. VAN NOSTRAND,

23 MURRAY STREET AND 27 WARREN STREET,

NEW YORK.

FRANCIS. Lowell Hydraulic Experiments, being a selection from Experiments on Hydraulic Motors, on the Flow of Water over Weirs, in Open Canals of Uniform Rectangular Section, and through submerged Orifices and diverging Tubes. Made at Lowell, Massachusetts. By James B. Francis, C. E. 2d edition, revised and enlarged, with many new experiments, and illustrated with twenty-three copperplate engravings. 1 vol. 4to, cloth......................	$15 00
ROEBLING (J. A.) Long and Short Span Railway Bridges. By John A. Roebling, C. E. Illustrated with large copperplate engravings of plans and views. Imperial folio, cloth............................	25 00
CLARKE (T. C.) Description of the Iron Railway Bridge over the Mississippi River, at Quincy, Illinois. By Thomas Curtis Clarke, Chief Engineer. Illustrated with 21 lithographed plans. 1 vol. 4to, cloth..	7 50
TUNNER (P.) A Treatise on Roll-Turning for the Manufacture of Iron. By Peter Tunner. Translated and adapted by John B. Pearse, of the Penn-	

ylvania Steel Works, with numerous engravings wood cuts and folio atlas of plates.	$10 00
ISHERWOOD (B. F.) Engineering Precedents for Steam Machinery. Arranged in the most practical and useful manner for Engineers. By B. F. Isherwood, Civil Engineer, U. S. Navy. With Illustrations. Two volumes in one. 8vo, cloth	$2 50
GILLMORE (Gen. Q. A,) Practical Treatise on the Construction of Roads, Streets, and Pavements. By Q. A. Gillmore, Lt.-Col. U. S Corps of Engineers, Brevet Major-Gen. U. S Army. With 70 illustrations. 12mo, cloth	2 00
—— Report on Strength of the Building Stones in the United States, etc. 8vo, illustrated, cloth	1 50
CAMPIN on the Construction of Iron Roofs. By Francis Campin. 8vo, with plates, cloth	2 00
COLLINS. The Private Book of Useful Alloys and Memoranda for Goldsmiths, Jewellers, &c. By James E. Collins. 18mo, cloth	50
CIPHER AND SECRET LETTER AND TELEGRAPHIC CODE, with Hogg's Improvements. The most perfect secret code ever invented or discovered. Impossible to read without the key. By C. S. Larrabee. 18mo, cloth	1 00
COLBURN. The Gas Works of London. By Zerah Colburn, C. E. 1 vol 12mo, boards	60
CRAIG (B. F.) Weights and Measures. An account of the Decimal System, with Tables of Conversion for Commercial and Scientific Uses. By B. F. Craig, M.D. 1 vol. square 32mo, limp cloth	50
NUGENT. Treatise on Optics; or, Light and Sight, theoretically and practically treated; with the application to Fine Art and Industrial Pursuits. By E. Nugent. With one hundred and three illustrations. 12mo, cloth	1 50
FREE HAND DRAWING. A Guide to Ornamental Figure and Landscape Drawing. By an Art Student. 18mo, boards,	50

HOWARD. Earthwork Mensuration on the Basis of the Prismoidal Formulae. Containing simple and labor-saving method of obtaining Prismoidal contents directly from End Areas. Illustrated by Examples, and accompanied by Plain Rules for Practical Uses. By Conway R. Howard, C. E., Richmond, Va. Illustrated, 8vo, cloth	1 50
GRUNER. The Manufacture of Steel. By M. L. Gruner. Translated from the French, by Lenox Smith, with an appendix on the Bessamer process in the United States, by the translator. Illustrated by Lithographed drawings and wood cuts. 8vo, cloth	3 00
AUCHINCLOSS. Link and Valve Motions Simplified. Illustrated with 37 wood-cuts, and 21 lithographic plates, together with a Travel Scale, and numerous useful Tables. By W. S. Auchincloss. 8vo, cloth	3 00
VAN BUREN. Investigations of Formulas, for the strength of the Iron parts of Steam Machinery. By J. D. Van Buren, Jr., C. E. Illustrated, 8vo, cloth	2 00
JOYNSON. Designing and Construction of Machine Gearing. Illustrated, 8vo, cloth	2 00
GILLMORE. Coignet Beton and other Artificial Stone. By Q. A. Gillmore, Major U. S. Corps Engineers. 9 plates, views, &c. 8vo, cloth	2 50
SAELTZER. Treatise on Acoustics in connection with Ventilation. By Alexander Saeltzer, Architect. 12mo, cloth	2 00
BUTLER (W. F.) Ventilation of Buildings. By W. F. Butler. With illustrations. 18mo, boards	50
DICTIONARY of Manufactures, Mining, Machinery, and the Industrial Arts. By George Dodd. 12mo, cloth	1 50
BOW. A Treatise on Bracing, with its application to Bridges and other Structures of Wood or Iron. By Robert Henry Bow, C. E. 156 illustrations, 8vo, cloth	1 50
BARBA (J.) The Use of Steel for Constructive Purposes; Method of Working, Applying, and Testing Plates and Brass. With a Preface by A. L. Holley, C. E. 12mo, cloth	1 50

GILLMORE (Gen. Q. A.) Treatise on Limes, Hydraulic Cements, and Mortars. Papers on Practical Engineering, U. S. Engineer Department, No. 9, containing Reports of numerous Experiments conducted in New York City, during the years 1858 to 1861, inclusive. By Q. A. Gillmore, Bvt. Maj.-Gen., U. S. A., Major, Corps of Engineers. With numerous illustrations. 1 vol, 8vo, cloth...............	$4 00
HARRISON. The Mechanic's Tool Book, with Practical Rules and Suggestions for Use of Machinists, Iron Workers, and others. By W. B. Harrison, associate editor of the "American Artisan." Illustrated with 44 engravings. 12mo, cloth............	1 50
HENRICI (Olaus). Skeleton Structures, especially in their application to the Building of Steel and Iron Bridges. By Olaus Henrici. With folding plates and diagrams. 1 vol. 8vo, cloth...................	1 50
HEWSON (Wm.) Principles and Practice of Embanking Lands from River Floods, as applied to the Levees of the Mississippi. By William Hewson, Civil Engineer. 1 vol. 8vo, cloth......................	2 00
HOLLEY (A. L.) Railway Practice. American and European Railway Practice, in the economical Generation of Steam, including the Materials and Construction of Coal-burning Boilers, Combustion, the Variable Blast, Vaporization, Circulation, Superheating, Supplying and Heating Feed-water, etc., and the Adaptation of Wood and Coke-burning Engines to Coal-burning; and in Permanent Way, including Road-bed, Sleepers, Rails, Joint-fastenings, Street Railways, etc., etc. By Alexander L. Holley, B. P. With 77 lithographed plates. 1 vol. folio, cloth....	12 00
KING (W. H.) Lessons and Practical Notes on Steam, the Steam Engine, Propellers, etc., etc., for Young Marine Engineers, Students, and others. By the late W. H. King, U. S. Navy. Revised by Chief Engineer J. W. King, U. S. Navy. Nineteenth edition, enlarged. 8vo, cloth........................	2 00
MINIFIE (Wm.) Mechanical Drawing. A Text-Book of Geometrical Drawing for the use of Mechanics	

and Schools, in which the Definitions and Rules of Geometry are familiarly explained; the Practical Problems are arranged, from the most simple to the more complex, and in their description technicalities are avoided as much as possible. With Illustrations for Drawing Plans, Sections, and Elevations of Buildings and Machinery; an Introduction to Isometrical Drawing, and an Essay on Linear Perspective and Shadows. Illustrated with over 200 diagrams engraved on steel. By Wm. Minifie, Architect. Ninth edition. With an Appendix on the Theory and Application of Colors. 1 vol. 8vo, cloth.............. $4 00

"It is the best work on Drawing that we have ever seen, and is especially a text-book of Geometrical Drawing for the use of Mechanics and Schools. No young Mechanic, such as a Machinist, Engineer, Cabinet-maker, Millwright, or Carpenter, should be without it."—*Scientific American.*

——— Geometrical Drawing. Abridged from the octavo edition, for the use of Schools. Illustrated with 48 steel plates. Fifth edition. 1 vol. 12mo, cloth.... 2 00

STILLMAN (Paul.) Steam Engine Indicator, and the Improved Manometer Steam and Vacuum Gauges—their Utility and Application. By Paul Stillman. New edition. 1 vol. 12mo, flexible cloth........... 1 00

SWEET (S. H.) Special Report on Coal; showing its Distribution, Classification, and cost delivered over different routes to various points in the State of New York, and the principal cities on the Atlantic Coast. By S. H. Sweet. With maps, 1 vol. 8vo, cloth..... 3 00

WALKER (W. H.) Screw Propulsion. Notes on Screw Propulsion: its Rise and History. By Capt. W. H. Walker, U. S. Navy. 1 vol. 8vo, cloth..... 75

WARD (J. H.) Steam for the Million. A popular Treatise on Steam and its Application to the Useful Arts, especially to Navigation. By J. H. Ward, Commander U. S. Navy. New and revised edition. 1 vol. 8vo, cloth.................................. 1 00

WIESBACH (Julius). A Manual of Theoretical Mechanics. By Julius Weisbach, Ph. D. Translated from the fourth augmented and improved German edition, with an Introduction to the Calculus, by Eckley B. Coxe, A. M., Mining Engineer. 1,100 pages, and 902 wood-cut illustrations. 8vo, cloth 10 00

DIEDRICH. The Theory of Strains, a Compendium for the calculation and construction of Bridges, Roofs, and Cranes, with the application of Trigonometrical Notes, containing the most comprehensive information in regard to the Resulting strains for a permanent Load, as also for a combined (Permanent and Rolling) Load. In two sections, adadted to the requirements of the present time. By John Diedrich, C. E. Illustrated by numerous plates and diagrams. 8vo, cloth.................................. 5

WILLIAMSON (R. S.) On the use of the Barometer on Surveys and Reconnoissances. Part I. Meteorology in its Connection with Hypsometry. Part II. Barometric Hypsometry. By R. S. Wiliamson, Bvt Lieut.-Col. U. S. A., Major Corps of Engineers. With Illustrative Tables and Engravings. Paper No. 15, Professional Papers, Corps of Engineers. 1 vol. 4to, cloth.................................. 15

POOK (S. M.) Method of Comparing the Lines and Draughting Vessels Propelled by Sail or Steam. Including a chapter on Laying off on the Mould-Loft Floor. By Samuel M. Pook, Naval Constructor. 1 vol. 8vo, with illustrations, cloth............ 5

ALEXANDER (J. H.) Universal Dictionary of Weights and Measures, Ancient and Modern, reduced to the standards of the United States of America. By J. H. Alexander. New edition, enlarged. 1 vol. 8vo, cloth.................................. 3

WANKLYN. A Practical Treatise on the Examination of Milk, and its Derivatives, Cream, Butter and Cheese. By J. Alfred Wanklyn, M. R. C. S., 12mo cloth.................................. 1

RICHARDS' INDICATOR. A Treatise on the Richards Steam Engine Indicator, with an Appendix by F. W. Bacon, M. E. 18mo, flexible, cloth.......... 1

PORTER (C. T.) A Treatise on the Richards Steam Engine Indicator, and the Development and Application of Force in the Steam Engine. By Charles T. Porter. Third edition, revised and enlarged. 8vo, illustrated, cloth.................................. 3

OPE. Modern Practice of the Electric Telegraph. A Hand Book for Electricians and operators. By Frank L. Pope. Ninth edition, revised and enlarged, and fully illustrated. 8vo, cloth........................ $2 00

"There is no other work of this kind in the English language that contains in so small a compass so much practical information in the application of galvanic electricity to telegraphy. It should be in the hands of every one interested in telegraphy, or the use of Batteries for other purposes."

EASSIE (P. B.) Wood and its Uses. A Hand-Book for the use of Contractors, Builders, Architects, Engineers, and Timber Merchants. By P. B. Eassie. Upwards of 250 illustrations. 8vo, cloth........... 1 50

SABINE. History and Progress of the Electric Telegraph, with descriptions of some of the apparatus. By Robert Sabine, C. E. Second edition, with additions, 12mo, cloth............................ 1 25

BLAKE. Ceramic Art. A Report on Pottery, Porcelain, Tiles, Terra Cotta and Brick. By W. P. Blake, U. S. Commissioner, Vienna Exhibition, 1873. 8vo, cloth.. 2 00

BENET. Electro-Ballistic Machines, and the Schultz Chronoscope. By Lieut.-Col. S. V. Benet, Captain of Ordnance, U. S. Army. Illustrated, second edition, 4to, cloth................................ 3 00

MICHAELIS. The Le Boulenge Chronograph, with three Lithograph folding plates of illustrations. By Brevet Captain O. E. Michaelis, First Lieutenant Ordnance Corps, U. S. Army, 4to, cloth.......... 3 00

ENGINEERING FACTS AND FIGURES An Annual Register of Progress in Mechanical Engineering and Construction, for the years 1863, 64, 65, 66, 67, 68. Fully illustrated, 6 vols. 18mo, cloth, $2.50 per vol., each volume sold separately.............

HAMILTON. Useful Information for Railway Men. Compiled by W. G. Hamilton, Engineer. Sixth edition, revised and enlarged, 562 pages Pocket form. Morocco, gilt.................................... 2 00

STUART (B.) How to Become a Successful Engineer. Being Hints to Youths intending to adopt the Profession. Sixth edition. 12mo, boards............. 50

STUART. **The Civil and Military Engineers of America. By Gen. C. B. Stuart. With 9 finely executed portraits of eminent engineers, and illustrated by engravings of some of the most important works constructed in America. 8vo, cloth.** $5 00

STONEY. **The Theory of Strains in Girders and similar structures, with observations on the application of Theory to Practice, and Tables of Strength and other properties of Materials. By Bindon B. Stoney, B. A. New and revised edition, enlarged, with numerous engravings on wood, by Oldham. Royal 8vo, 664 pages. Complete in one volume. 8vo, cloth.** 12 50

SHREVE. **A Treatise on the Strength of Bridges and Roofs. Comprising the determination of Algebraic formulas for strains in Horizontal, Inclined or Rafter, Triangular, Bowstring, Lenticular and other Trusses, from fixed and moving loads, with practical applications and examples, for the use of Students and Engineers. By Samuel H. Shreve, A. M., Civil Engineer.** 87 wood-cut illustrations. **2d edition. 8vo, cloth...** 5 00

MERRILL. Iron Truss Bridges for Railroads. The method of calculating strains in Trusses, with a careful comparison of the most prominent Trusses, in reference to economy in combination, etc., etc. By Brevet Col. William E. Merrill, U. S. A., Major Corps of Engineers, with nine lithographed plates of Illustrations. 4to, cloth 5 00

WHIPPLE. An Elementary and Practical Treatise on Bridge Building. An enlarged and improved edition of the author's original work. By S. Whipple, C. E., inventor of the Whipple Bridges, &c. Illustrated 8vo, cloth 4 00

THE KANSAS CITY BRIDGE. With an account of the Regimen of the Missouri River, and a description of the methods used for Founding in that River. By O. Chanute, Chief Engineer, and George Morrison, Assistant Engineer. Illustrated with five lithographic views and twelve plates of plans. 4to, cloth, 6 00

DUBOIS (A. J.) The New Method of Graphical Statics. By A. J. Dubois, C. E., Ph. D. With 60 illustrations. 8vo, cloth 2 00

MAC CORD. A Practical Treatise on the Slide Valve by Eccentrics, examining by methods the action of the Eccentric upon the Slide Valve, and explaining the Practical processes of laying out the movements, adapting the valve for its various duties in the steam engine. For the use of Engineers, Draughtsmen, Machinists, and Students of Valve Motions in general. By C. W. Mac Cord, A. M., Professor of Mechanical Drawing, Stevens' Institute of Technology, Hoboken, N. J. Illustrated by 8 full page copperplates. 4to, cloth.............................. $3 00

KIRKWOOD. Report on the Filtration of River Waters, for the supply of cities, as practised in Europe, made to the Board of Water Commissioners of the City of St. Louis. By James P. Kirkwood. Illustrated by 30 double plate engravings. 4to, cloth, 15 00

PLATTNER. Manual of Qualitative and Quantitative Analysis with the Blow Pipe. From the last German edition, revised and enlarged. By Prof. Th. Richter, of the Royal Saxon Mining Academy. Translated by Prof. H. B. Cornwall, Assistant in the Columbia School of Mines, New York assisted by John H. Caswell. Illustrated with 87 wood cuts, and one lithographic plate. Third edition, revised, 560 pages, 8vo, cloth. Price reduced.......................... 5 00

PLYMPTON. The Blow Pipe. A Guide to its Use in the Determination of Salts and Minerals. Compiled from various sources, by George W. Plympton, C. E. A. M., Professor of Physical Science in the Polytechnic Institute, Brooklyn, New York, 12mo, cloth.. 1 50

PYNCHON. Introduction to Chemical Physics, designed for the use of Academies, Colleges and High Schools. Illustrated with numerous engravings, and containing copious experiments with directions for preparing them. By Thomas Ruggles Pynchon, M. A., Professor of Chemistry and the Natural Sciences, Trinity College, Hartford New edition, revised and enlarged and illustrated by 269 illustrations on wood. Crown, 8vo. cloth...................... 3 00

ELIOT AND STORER. A compendious Manual of Qualitative Chemical Analysis. By Charles W. Eliot and Frank H. Storer. Revised with the Co-operation of the authors. By William R. Nichols, Professor of Chemistry in the Massachusetts Institute of Technology. Illustrated, 12mo, cloth....... $1

RAMMELSBERG. Guide to a course of Quantitative Chemical Analysis, especially of Minerals and Furnace Products. Illustrated by Examples. By C. F. Rammelsberg. Translated by J. Towler, M. D. 8vo, cloth.. 2

DOUGLASS and PRESCOTT. Qualitative Chemical Analysis. A Guide in the Practical Study of Chemistry, and in the Work of Analysis. By S. H. Douglass and A. B. Prescott, of the University of Michigan. New edition. 8vo, cloth.................... 3

JACOB. On the Designing and Construction of Storage Reservoirs, with Tables and Wood Cuts representing Sections, &c., 18mo, boards.......................

WATT'S Dictionary of Chemistry. New and Revised edition complete in 6 vols. 8vo cloth, $62.00. Supplementary volume sold separately. Price, cloth... 9

RANDALL. Quartz Operators Hand-Book. By P. M. Randall. New edition, revised and enlarged, fully illustrated. 12mo, cloth 2

SILVERSMITH. A Practical Hand-Book for Miners, Metallurgists, and Assayers, comprising the most recent improvements in the disintegration, amalgamation, smelting, and parting of the Precious ores, with a comprehensive Digest of the Mining Laws. Greatly augmented, revised and corrected. By Julius Silversmith. Fourth edition. Profusely illustrated. 12mo, cloth.. 3

THE USEFUL METALS AND THEIR ALLOYS, including Mining Ventilation, Mining Jurisprudence, and Metallurgic Chemistry employed in the conversion of Iron, Copper, Tin, Zinc, Antimony and Lead ores, with their applications to the Industrial Arts. By Scoffren, Truan, Clay, Oxland, Fairbairn, and others. Fifth edition, half calf..................... 3

JOYNSON. The Metals used in construction, Iron, Steel, Bessemer Metal, etc., etc. By F. H. Joynson. Illustrated, 12mo, cloth..........................	$0 75
VON COTTA. Treatise on Ore Deposits. By Bernhard Von Cotta, Professor of Geology in the Royal School of Mines, Freidberg, Saxony. Translated from the second German edition, by Frederick Prime, Jr., Mining Engineer, and revised by the author, with numerous illustrations. 8vo, cloth.......	4 00
GREENE. Graphical Method for the Analysis of Bridge Trusses, extended to continuous Girders and Draw Spans. By C. E. Greene, A. M., Prof. of Civil Engineering, University of Michigan. Illustrated by 3 folding plates, 8vo, cloth..........................	2 00
BELL. Chemical Phenomena of Iron Smelting. An experimental and practical examination of the circumstances which determine the capacity of the Blast Furnace, The Temperature of the air, and the proper condition of the Materials to be operated upon. By I. Lowthian Bell. 8vo, cloth............	6 00
ROGERS. The Geology of Pennsylvania. A Government survey, with a general view of the Geology of the United States, Essays on the Coal Formation and its Fossils, and a description of the Coal Fields of North America and Great Britain. By Henry Darwin Rogers, late State Geologist of Pennsylvania, Splendidly illustrated with Plates and Engravings in the text. 3 vols., 4to, cloth. with Portfolio of Maps.	30 00
BURGH. Modern Marine Engineering, applied to Paddle and Screw Propulsion. Consisting of 36 colored plates, 259 Practical Wood Cut Illustrations, and 403 pages of descriptive matter, the whole being an exposition of the present practice of James Watt & Co., J. & G. Rennie, R. Napier & Sons, and other celebrated firms, by N. P. Burgh, Engineer, thick 4to, vol., cloth, $25.00; half mor........	30 00
CHURCH. Notes of a Metallurgical Journey in Europe. By J. A. Church, Engineer of Mines, 8vo, cloth.....	2 00

BOURNE. Treatise on the Steam Engine in its various applications to Mines, Mills, Steam Navigation, Railways, and Agriculture, with the theoretical investigations respecting the Motive Power of Heat, and the proper proportions of steam engines. Elaborate tables of the right dimensions of every part, and Practical Instructions for the manufacture and management of every species of Engine in actual use. By John Bourne, being the ninth edition of "A Treatise on the Steam Engine," by the "Artizan Club." Illustrated by 38 plates and 546 wood cuts. 4to, cloth..........	$15 00
STUART. The Naval Dry Docks of the United States. By Charles B. Stuart late Engineer-in-Chief of the U. S. Navy. Illustrated with 24 engravings on steel. Fourth edition, cloth..........	6 00
ATKINSON. Practical Treatises on the Gases met with in Coal Mines. 18mo, boards..........	50
FOSTER. Submarine Blasting in Boston Harbor, Massachusetts. Removal of Tower and Corwin Rocks. By J. G. Foster, Lieut.-Col. of Engineers, U. S. Army. Illustrated with seven plates, 4to, cloth..........	3 50
BARNES Submarine Warfare, offensive and defensive, including a discussion of the offensive Torpedo System, its effects upon Iron Clad Ship Systems and influence upon future naval wars. By Lieut.-Commander J. S. Barnes, U. S. N., with twenty lithographic plates and many wood cuts. 8vo, cloth... .	5 00
HOLLEY. A Treatise on Ordnance and Armor, embracing descriptions, discussions, and professional opinions concerning the materials, fabrication, requirements, capabilities, and endurance of European and American Guns, for Naval, Sea Coast, and Iron Clad Warfare, and their Rifling, Projectiles, and Breech-Loading; also, results of experiments against armor, from official records, with an appendix referring to Gun Cotton, Hooped Guns, etc., etc. By Alexander L. Holley, B. P., 948 pages, 493 engravings, and 147 Tables of Results, etc., 8vo, half roan.	10 00

SIMMS. A Treatise on the Principles and Practice of Levelling, showing its application to purposes of Railway Engineering and the Construction of Roads, &c. By Frederick W. Simms, C. E. From the 5th London edition, revised and corrected, with the addition of Mr. Laws's Practical Examples for setting out Railway Curves. Illustrated with three Lithographic plates and numerous wood cuts. 8vo, cloth.	$2 50
BURT. Key to the Solar Compass, and Surveyor's Companion; comprising all the rules necessary for use in the field; also description of the Linear Surveys and Public Land System of the United States, Notes on the Barometer, suggestions for an outfit for a survey of four months, etc. By W. A. Burt, U. S. Deputy Surveyor. Second edition. Pocket book form, tuck..	2 50
THE PLANE TABLE. Its uses in Topographical Surveying, from the Papers of the U. S. Coast Survey. Illustrated, 8vo, cloth........................	2 00
"This work gives a description of the Plane Table, employed at the U. S. Coast Survey office, and the manner of using it."	
JEFFER'S. Nautical Surveying. By W. N. Jeffers, Captain U. S. Navy. Illustrated with 9 copperplates and 31 wood cut illustrations. 8vo, cloth...........	5 00
CHAUVENET. New method of correcting Lunar Distances, and improved method of Finding the error and rate of a chronometer, by equal altitudes. By W. Chauvenet, LL.D. 8vo, cloth..................	2 00
BRUNNOW. Spherical Astronomy. By F. Brunnow, Ph. Dr. Translated by the author from the second German edition. 8vo, cloth......................	6 50
PEIRCE. System of Analytic Mechanics. By Benjamin Peirce. 4to, cloth..........................	10 00
COFFIN. Navigation and Nautical Astronomy. Prepared for the use of the U. S. Naval Academy. By Prof. J. H. C. Coffin. Fifth edition. 52 wood cut illustrations. 12mo, cloth............................	3 50
NOBLE (W. H.) Useful Tables. Compiled by W. H. Noble, M. A., Captain Royal Artillery. Pocket form, cloth.....................................	50

CLARK. Theoretical Navigation and Nautical Astronomy. By Lieut. Lewis Clark, U. S. N. Illustrated with 41 wood cuts. 8vo, cloth	$3 00
HASKINS. The Galvanometer and its Uses. A Manual for Electricians and Students. By C. H. Haskins. 12mo, pocket form, morocco.	2 00
MORRIS (E.) Easy Rules for the Measurement of Earthworks, by Means of the Prismoidal Formula. By Ellwood Morris, C. E. 78 illustrations. 8vo, cloth	1 50
BECKWITH. Observations on the Materials and Manufacture of Terra-Cotta, Stone Ware, Fire Brick, Porcelain and Encaustic Tiles, with remarks on the products exhibited at the London International Exhibition, 1871. By Arthur Beckwith, C. E. 8vo, paper	60
MORFIT. A Practical Treatise on Pure Fertilizers, and the chemical conversion of Rock Guano, Marlstones, Coprolites, and the Crude Phosphates of Lime and Alumina generally, into various valuable products. By Campbell Morfit, M.D., with 28 illustrative plates, 8vo, cloth	20 00
BARNARD. The Metric System of Weights and Measures. An address delivered before the convocation of the University of the State of New York, at Albany, August, 1871. By F. A. P. Barnard, LL.D., President of Columbia College, New York. Second edition from the revised edition, printed for the Trustees of Columbia College. Tinted paper, 8vo, cloth	3 00
—— Report on Machinery and Processes on the Industrial Arts and Apparatus of the Exact Sciences. By F. A. P. Barnard, LL.D. Paris Universal Exposition, 1867. Illustrated, 8vo, cloth	5 00
ALLAN. Theory of Arches. By Prof. W. Allan, formerly of Washington & Lee University, 18mo, b'rds	50
ALLAN (Prof W.) Strength of Beams under Transverse Loads. By Prof. W. Allan, author of "Theory of Arches." With illustrations. 18mo, boards	50

MOTT (H. A., Jr.) The Chemists' Manual. A Practical Treatise on Chemistry, Qualitative and Quantitative Analysis, Stoichiometry, Blow Pipe Analysis, Mineralogy, Assaying, Toxicology, etc., etc. By Henry A. Mott, Jr., E. M., Ph. D. 8vo, cloth....	6 00
WILLIAMSON. Practical Tables in Meteorology and Hypsometry, in connection with the use of the Barometer. By Col. R. S. Williamson, U. S. A. 4to, cloth..	2 50
CLEVENGER. A Treatise on the Method of Government Surveying, as prescribed by the U. S. Congress and Commissioner of the General Land Office, with complete Mathematical, Astronomical and Practical Instructions for the Use of the United States Surveyors in the Field. By S. R. Clevenger, Pocket Book Form, Morocco..............................	2 50
FANNING. Water Supply Engineering. A Treatise on the Theory and Practice of Gathering and Storing Water for Power and Domestic Use, Clarification of Water in Pipes and Canals, Raising of Water by Power, and on the Practical Construction of Reservoir Weirs, Dams, and Pipe Systems. By J. T. Fanning, C. E. With 150 illustrations. 8vo, cloth. *In press.*	
HUNT. Designs for the Gateways of the Southern Entrances to the Central Park. By Richard M. Hunt. With a description of the designs. 4to. cloth......	5 00
LAZELLE. One Law in Nature. By Capt. H. M. Lazelle, U. S. A. A new Corpuscular Theory, comprehending Unity of Force, Identity of Matter, and its Multiple Atom Constitution, applied to the Physical Affections or Modes of Energy. 12mo, cloth...	1 50
CORFIELD. Water and Water Supply. By W. H Corfield, M. A. M, D., Professor of Hygiene and Public Health at University College. London. 18mo, boards	50
ROWAN on Boiler Incrustation and Corrosion. By F. J. Rowan. 18mo, boards........................	50

BOYNTON. History of West Point, its Military Importance during the American Revolution, and the Origin and History of the U. S. Military Academy. By Bvt. Major C. E. Boynton, A.M., Adjutant of the Military Academy. Second edition, 416 pp. 8vo, printed on tinted paper, beautifully illustrated with 36 maps and fine engravings, chiefly from photographs taken on the spot by the author. Extra cloth..........	$3 50
WOOD. West Point Scrap Book, being a collection of Legends, Stories, Songs, etc., of the U. S. Military Academy. By Lieut. O. E. Wood, U. S. A. Illustrated by 69 engravings and a copperplate map. Beautifully printed on tinted paper. 8vo, cloth.....	5 00
WEST POINT LIFE. A Poem read before the Dialectic Society of the United States Military Academy. Illustrated with Pen-and-Ink Sketches. By a Cadet. To which is added the song, "Benny Havens, oh!" oblong 8vo, 21 full page illustrations, cloth..........	2 50
GUIDE TO WEST POINT and the U. S. Military Academy, with maps and engravings, 18mo, blue cloth, flexible..........	1 00
HENRY. Military Record of Civilian Appointments in the United States Army. By Guy V. Henry, Brevet Colonel and Captain First United States Artillery, Late Colonel and Brevet Brigadier General, United States Volunteers. Vol. 1 now ready. Vol. 2 in press. 8vo, per volume, cloth..........	5 00
HAMERSLY. Records of Living Officers of the U. S. Navy and Marine Corps. Compiled from official sources. By Lewis B. Hamersly, late Lieutenant U. S. Marine Corps. Revised edition, 8vo, cloth...	5 00
MOORE. Portrait Gallery of the War. Civil, Military and Naval. A Biographical record, edited by Frank Moore. 60 fine portraits on steel. Royal 8vo, cloth..........	6 00

PRESCOTT. Outlines of Proximate Organic Analysis, for the Identification, Separation, and Quantitative Determination of the more commonly occurring Organic Compounds. By Albert B. Prescott, Professor of Chemistry, University of Michigan, 12mo, cloth... 1 75

PRESCOTT. Chemical Examination of Alcoholic Liquors. A Manual of the Constituents of the Distilled Spirits and Fermented Liquors of Commerce, and their Qualitative and Quantitative Determinations. By Albert B. Prescott, 12mo, cloth.................. 1 50

NAQUET. Legal Chemistry. A Guide to the Detection of Poisons, Falsification of Writings, Adulteration of Alimentary and Pharmaceutical Substances; Analysis of Ashes, and examination of Hair, Coins, Arms and Stains, as applied to Chemical Jurisprudence, for the Use of Chemists, Physicians, Lawyers, Pnarmacists and Experts Translated with additions, including a list of books and Memoirs on Texicology, etc. from the French of A. Naquet. By J. P. Battershall, Ph. D. with a preface by C. F. Chandler, Ph. D., M. D,, L. L. D. 12mo, cloth.... 2 00

McCULLOCH. Elementary Treatise on the Mechanical Theory of Heat, and its application to Air and Steam Engines. By R. S. McCulloch, 8vo, cloth.... 3 50

AXON. The Mechanics Friend; a Collection of Receipts and Practical Suggestions Relating to Aquaria—Bronzing—Cements—Drawing—Dyes—Electricity—Gilding—Glass Working—Glues—Horology—Lacquers—Locomotives—Magnetism—Metal-Working—Modelling—Photography—Pyrotechy—Railways—Solders—Steam Engine—Telegraphy—Taxidermy—Varnishes—Water-Proofing and Miscellaneous Tools,—Instruments, Machines and Processes connected with the Chemical and Mechanics Arts; with numerous diagrams and wood cuts. Edited by William **E. A. Axon.** Fancy cloth.................... 1 50

STAHL. Transmission of Power. By Wire Ropes. By A. W. Stahl. 18mo, boards.................. 50

ERNST. Manual of Practical Military Engineering, Prepared for the use of the Cadets of the U. S. Military Academy, and for Engineer Troops. By Capt. O. H. Ernst, Corps of Engineers, Instructor in Practical Military Engineering, U. S. Military Academy. 192 wood cuts and 3 lithographed plates. 12mo, cloth.. 5 00

BUTLER. Projectiles and Rifled Cannon. A Critical Discussion of the Principal Systems of Rifling and Projectiles, with Practical Suggestions for their Improvement, as embraced in a Report to the Chief of Ordnance, U. S. A. By Capt. John S. Butler, Ordnance Corps, U. S. A. 36 plates, 4to, cloth........ 7 50

BLAKE. Report upon the Precious Metals: Being Statistical Notices of the principal Gold and Silver producing regions of the World, Represented at the Paris Universal Exposition. By William P. Blake, Commissioner from the State of California. 8vo, cloth 2 00

TONER. Dictionary of Elevations and Climatic Register of the United States. Containing in addition to Elevations, the Latitude, Mean, Annual Temperature, and the total Annual Rain fall of many localities; with a brief introduction on the Orographic and Physical Peculiarities of North America. By J. M. Toner, M. D. 8vo, cloth.................................... 3 75

MOWBRAY. Tri-Nitro Glycerine, as applied in the Hoosac Tunnel, and to Submarine Blasting, Torpedoes, Quarrying, etc. Being the result of six year's observation and practice during the manufacture of five hundred thousand pounds of this explosive Mica, Blasting Powder, Dynamites; with an account of the various Systems of Blasting by Electricity, Priming Compounds, Explosives, etc., etc. By George M. Mowbray, Operative Chemist, with thirteen illustrations, tables and appendix. Third Edition. Re-written. 8vo. cloth................................ 3 00

WEYRAUCH. Strength and Calculations of Dimensions of Iron and Steel Constructions. By J. J. Weyrauch, 12mo, cloth................ 1 00

JAN 9 - 1936